

Draft Report

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Basin F Reduction

on

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Commerce City, Colorado

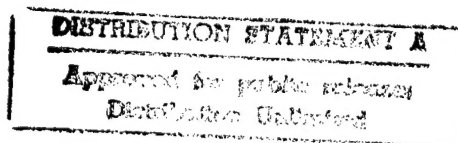
ALTERNATIVES FOR REDUCTION IN VOLUME OF  
LIQUID IN BASIN F, ROCKY MOUNTAIN ARSENAL

to

U.S. Army Toxic & Hazardous Materials Agency  
Aberdeen Proving Ground, MD

by

Dr. Gary McKown  
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March 27, 1980



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INTRODUCTION

Objective

The objective of this study is to research and evaluate alternatives for reducing the volume of liquid waste contained in Basin F at Rocky Mountain Arsenal (RMA), Colorado. Three feasible candidate processes were to be recommended with supporting rationale and identity of further research and development requirements.

Authority

This work is authorized by Task 2, Contract Number DAAK11-79-C-0148 to AAI Corporation and subsequent subcontract to Battelle Columbus Laboratories, number 500700.

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### Disclaimers

The findings in this report are not to be construed as an official Department of Army position unless so designated by other authorized documents.

The use of trade names in this report does not constitute an official endorsement or approval of the use of such commercial hardware or software.

The information in this document has not been cleared for release to the general public.

### Acknowledgements

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### Background

The history of and prior activities associated with Basin F has been described.<sup>(1)</sup> The basin consists of an approximately 36.4 hectare (90 acre) impoundment with a current liquid content of  $3.2 \times 10^8$  liters (84million gallons). The estimated surface area of the lake at present is 25 hectares (62 acres). The chemical composition of the basin, as obtained from various studies through 1977, has been detailed.<sup>(2)</sup> Data showing major known constituency is given in Table 1.

Basin F is a highly suspected source of groundwater pollution in the RMA area.<sup>(2-4)</sup> The U.S. Army has developed plans for containment of source contamination and for reducing the potential of Basin F contents to enter the aquifer systems underlying the lake.<sup>(5-7)</sup> Current plans for accomplishment of the latter is to eliminate the liquid contents, fill the basin with suitable material, and place a relatively impermeable clay cap on the surface. In addition, emplacement of a barrier to migration of subsurface contamination from the vicinity of Basin F is being considered. The present study was initiated in order to provide alternative techniques that might be installed to aid in elimination of the liquid content such that filling of the basin might be more readily accomplished.

TABLE 1. BASIN F CONSTITUENCY (MAJOR COMPONENTS)

Aldrin	205 ppb.		
Isodrin	<10		
Dieldrin	44 ppb.		
Endrin	21 ppb.		
Dithiane	54 ppb		
Dicylopentadiene	<10 ppb		
Diisopropylmethyl phosphonate	17 ppm		
Dimethylmethylphosphonate	1260 ppm		
Sulfuride	6 ppm		
Sulfone	~45 ppm		
Total Organics	~2.5%		
Chloride	52,000 ppm	Arsenic	1 ppm
Sulfate	24,000 ppm	Cyanide	1.5 ppm
Copper	730 ppm	Boron*	31 ppm
Iron	6 ppm	Cadmium*	42 ppm
Nitrogen	~130 ppm	Nickel	133 ppm
O-PO <sub>4</sub>	~120 ppm	Mercury	28 ppb
Total Phosphorus	2100 ppm		
Fluoride	115 ppm		
Sodium	36,000 ppm		
Hardness	2,500 ppm		
Residue	156,000 ppm		
COD	25,000		
TOC	22,000		

\* AEHA, 1973

## APPROACH

### Method

The general approach used in performance of this task was as follows:

- 1) Review of prior studies and data.
- 2) Generation of concepts for treatment.
- 3) Evaluation of potential techniques from the standpoint of feasibility, including technical, economic, time (schedule) and regulatory factors.
- 4) Determination of unresolved data requirements for selected methods.

### Specific Subtasks

The six subtasks into which the study was divided are as follows:

- 1) Preparation of a decision scheme which was used to evaluate candidate methods. A simple schematic of the most important qualitative criteria was developed for use in preliminary screening of concepts, see Figure 1. The goal here was to obtain a manageable number of options for further study. This was followed by evaluation according to the criteria listed in Figure 2, to yield three recommended systems.
- 2) A computerized literature search was performed from which candidate methods were selected. Pertinent references obtained therefrom are given with abstracts in Appendix A.
- 3) A review of U.S. Government publications provided by USATHAMA was conducted.<sup>(1-9)</sup> These reports provided information both on selected processes and as background against which techniques could be evaluated.
- 4) Candidate techniques were evaluated according to the criteria noted above.
- 5) Data gaps and requirements for further research and development were delineated.
- 6) Interim oral, draft and final written reports were provided.

- A. DOES PROCESS MEET OBJECTIVES?
- B. IS TECHNOLOGY SUFFICIENTLY DEVELOPED?
- C. DOES PROCESS MEET REGULATORY REQUIREMENTS?
- D. ARE MAJOR PERMIT PROBLEMS ANTICIPATED?
- E. IS APPLICATION TIME FRAME ACCEPTABLE?
- F. DOES PROCESS INTERFERE WITH CURRENT ARMY PLANS?
- G. ARE EXPECTED COSTS ACCEPTABLE?

Figure 1. Preliminary Screening Criteria

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- A. TECHNICAL ADEQUANCY, RISK AND RELIABILITY
- B. CONSTRUCTION AND OPERATING SCHEDULE
- C. COSTS: CAPITAL INVESTMENT AND OPERATIONAL
- D. REGULATION/PERMIT REQUIREMENTS
- E. R&D AND DATA ACQUISITION REQUIREMENTS
- F. SENSITIVITY OF EVALUATION TO DATA GAPS
- G. RELATION OF METHOD TO KNOWN ARMY PLANS
- H. ULTIMATE FATE OF CONTAMINATED MATERIALS
- I. ENERGY REQUIREMENTS
- J. ADVERSE EFFECTS AND ANTICIPATED PROBLEMS
- K. MAJOR ADVANTAGES TOWARD MEETING OBJECTIVES

Figure 2. Final Evaluation Criteria

### Restrictions and Limitations

During the course of the study, several guidelines were provided to Battelle as semiquantitative qualifications and factors that would ultimately influence selection of processes for further study. These are listed below and were considered at appropriate places during the evaluation process shown in Figures 1 and 2.

1. Time and schedule restraints. To augment current long-range plans of the U.S. Army in dealing with Basin F, any process developed for liquid elimination would be required to meet the time frames of  $1 \pm 1$  year for research, development and demonstrable proof of applicability and  $3 \pm 1$  years as a target for completion of the objective. This restriction implies limiting consideration to processes currently developed to beyond the bench or small pilot scale, i.e., readily fieldable techniques. This limitation resulted in elimination of many methods for which a great deal of engineering development would be required, or where gross uncertainties exist with regard to predictable results.
2. Techniques for which major problems in obtaining permits and in meeting other regulatory requirements would be expected are considered to be unacceptable. The results of a previous report <sup>(35)</sup> was relied upon heavily to resolve this controversy.
3. Methods such as use of spray rafts which result in highly visible operations are considered inexpedient from the socio-political standpoint.
4. Ultimate disposal or elimination of Basin F fluids as a polluting source must be addressed, i.e., it is considered inappropriate merely to exchange the Basin F problem for another disposal situation with consequences of similar magnitude. This factor eliminates from consideration such proposed treatment as use of a separate, secure reservoir; drumming and/or transport of the contents; and release of the material onto the surface or into disposal wells.

5. Air pollution arising from discharge of organic vapors from the lagoon is restricted to that which would occur via natural evaporation from a full basin.
6. Capital and operating costs for any proposed system are at least of secondary importance. A representative figure for investment costs of \$1M was provided. Energy-intensive methods should be over-inflated according to Corps of Engineers' guidelines.
7. A secondary objective of the task is to minimize the sub-surface contamination in the vicinity of Basin F.
8. It may be assumed that the current influx of wastewater into Basin F, amounting to 40-150 liters (10-40 gallons) per minute, will cease whenever any fluid reduction facility is installed, i.e., approximately  $2 \pm 1$  years from the current date.
9. In the absence of other beneficial factors, recovery of materials from the fluid was not considered economically feasible<sup>(8)</sup>.
10. The primary objective of the task is to reduce or eliminate the volume of liquid wastes. Accordingly, treatment methods which remove or decompose specific nonaqueous materials were considered only as they support achievement of that objective, A variety of schemes for ultimate disposal of the contents have been documented.<sup>(8,9)</sup>
11. Total effort on this task is limited to 8 weeks and 340 person-hours. Owing to the rather broad scope, the number of methods and techniques that required analysis, the amount of material to be digested, and the unexpected general lack of data regarding the properties of Basin F fluid, the depth of evaluation was perforce limited.

12. Based on best available information, the following general characteristics apply to the Basin F study:

- A. AT  $V = 110 \times 10^6$  GAL,  $D = 1.16$  (16% SOLIDS)
- B. PRESENT VOLUME =  $84 \times 10^6$  GALLONS
- C. NET EVAPORATION RATE = 350,000 GAL PER ACRE  
= 0.24 PER YEAR
- D. ENHANCEMENT REQUIRED  $\geq 50\%$  ( $13 \times 10^6$  GAL/YR)
- E. PRECIPITATION INFLUX =  $36 \times 10^6$  GAL/YR
- F. PLANT INFLUENT (EST.) =  $6 \times 10^6$  GAL PER YEAR
- G. AT  $V = 20 \times 10^6$  GAL.,  $D = 1.8-2.0$  (60% SOLIDS)
- H. A plot of lagoon surface area versus the volume of liquid is shown in Figure 3.



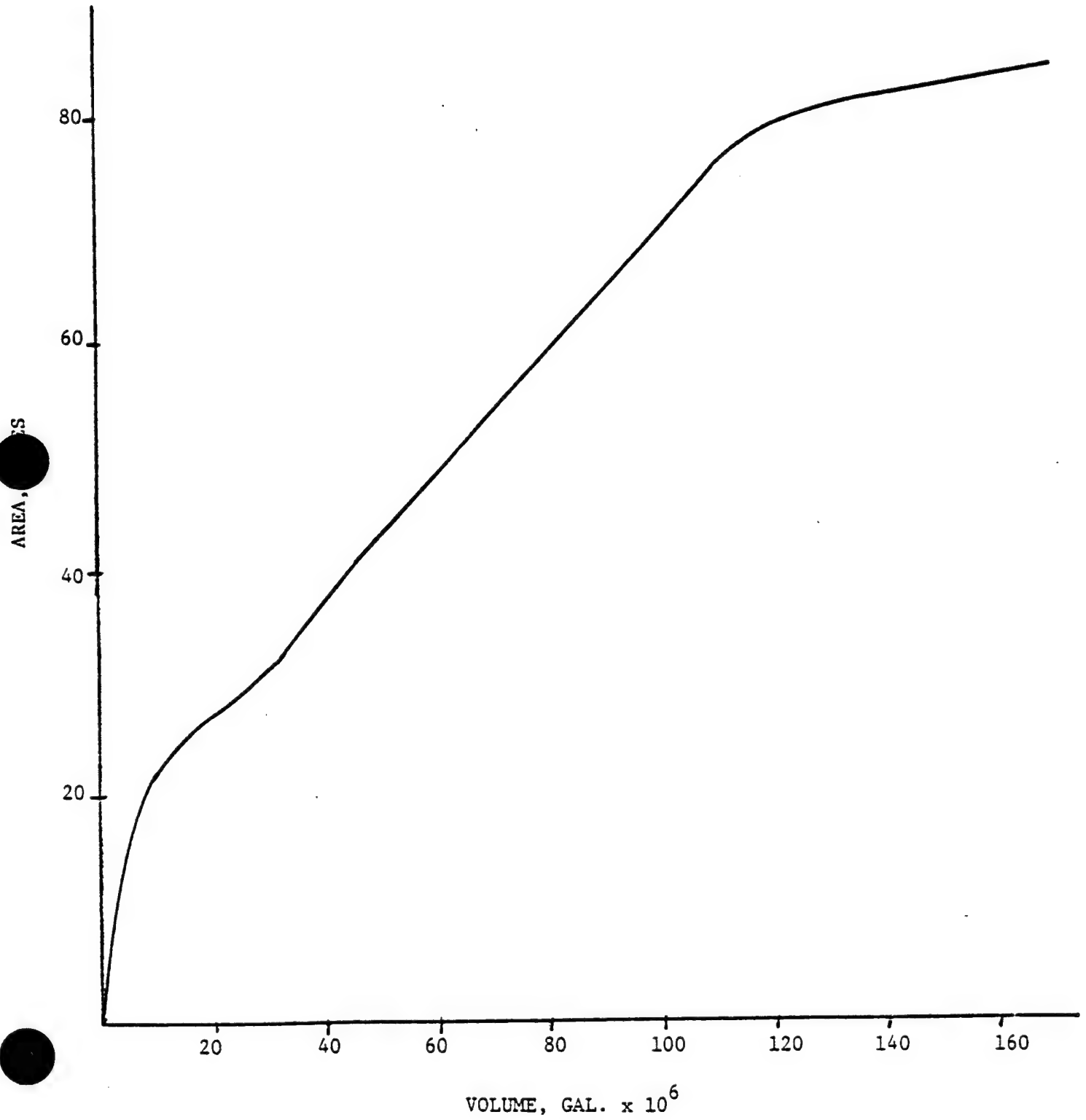


Figure 3. Basin F, Area vs Capacity

## SCREENING EVALUATION

### Biological Treatment

The treatment of municipal and industrial wastes by biological reactions is a common practice, (10, 11) and many types of systems have been developed and applied for removal of organic materials from waste streams. Biological disposal methods may be employed to reduce or eliminate any "biodegradable" waste material. This normally implies organic compounds which serve as a source of carbon for the microorganisms, but inorganic nutrients such as available nitrogen, phosphorous, etc. also can support biological reactions. Bacterial cultures, for example, have been shown to degrade most organophosphate insecticides.

Most biological degradation systems are aerobic in operation, and differences in design often are manifestations of methods for maintaining oxygen levels as high as possible in the reactor. Anaerobic systems, of which less development has occurred, require the absence of oxygen.

The problems associated with application of biological treatment to the Basin F situation are twofold:

- The reactivity and biodegradeability of the medium is unknown. The fluid is a complex mixture containing many compounds of known biodegradability, potentially intolerant levels of several toxic metals, other inorganic substrates, and a high concentration of sodium chloride. No evidence was found of studies dealing with the toxicity or potential treatment by organisms of Basin F wastes.

Salt solutions on the order of 3 percent have been shown to quickly render a biological process ineffective, (36) and a very large dilution of Basin F wastes (on the order of 100:1) would be required during treatment. This requirement significantly increases the liquid elimination problem, as well as creating the need for very large quantities ( 500,000 gpd) of relatively clean water.

Without a great deal of research beginning at the laboratory scale, any biological treatment proposal would involve considerable risk in attempting large scale application within the restricted time frames of the present case.

- Biological treatment may be used in one of two ways in connection with Basin F volume reduction; as the primary treatment technique with direct discharge of supernatant liquid to the surface or subsurface environment, or as a secondary treatment method to reduce intolerable pollutant levels arising from application of some other technique.

For primary treatment, assurances must be made that the effluent meets regulatory discharge requirements. With the number and levels of various Basin F constituents, it is felt that, at best, several years of research and development would be required before biological treatment alone could be applied to reducing the volume significantly.

Biological disposal technology may be of more direct applicability in controlling the levels of pollutants from other volume reduction processes. Examples of this are reduction of organic vapor emissions through either in situ biodegradation or by final cleanup of the discharge from another process.

Several biological treatment methods are considered to be innovative in nature, of such incomplete development status or too costly as to be precluded from further consideration. These include:

- Fluidized-bed bioreactor
- Deep tank/shaft extended aeration
- Activated carbon addition
- Pure oxygen systems
- Cooling tower bio-oxidation
- Anaerobic digestion. Uncertainty factors include odor production from reduction of sulfates, toxic metal effects, and temperature control requirements.

Conventional applications of biological treatment to industrial organic and hazardous wastes include the techniques of activated sludge, aeration basins, trickling filters, and soil incorporation.

Of these biological treatment processes, only land application is sufficiently assured of technical feasibility with moderate risk to be considered further, due to regulatory discharge problems and the very large potential for failure to adequately treat the highly saline waters.

#### Soil Incorporation

Land cultivation or soil incorporation disposal techniques have been practiced by pharmaceutical, tannery, paper and pulp, oil refinery and many other industries.(12, 13). Soil is a natural environment for deactivation and degradation of many hazardous materials through complex physical, biological and chemical processes. This method of disposal involves intimate mixing of the wastes with surface soil to promote decomposition, particularly of organics by microbial action. In addition, complex soil substrates have considerable retention characteristics for many metals and other hazardous components; in fact, most metals are relatively immobile in soils.

Direct land cultivation of the Basin F fluid cannot be ruled out easily. A simple calculation shows that if 1.25 cm (0.5 inch) of the waste is mixed into the top 12" of soil, approximately 6000 acres, or about one-third of the available RMA area, would be required to dispose of the entire Basin F liquid content. This process would also result in immediate dilution of all hazardous materials by a volume factor of 24:1. For example, 720 ppm of copper from the fluid when well mixed with the soil amounts to less than 30 ppm. Similar dilution of the organic wastes as well as total salts would almost certainly result in enhanced biodegradability and/or rapid incorporation into the soil structure. Note that the approximate 100-fold increase in surface area of the applied wastes also would accelerate evaporation of volatile organics, photochemical and air oxidation reactions. Toxic metal

contamination of the soils do not appear to be a major problem, with the possible exception of cadmium and copper. Table 2 shows averages and ranges of soil concentrations and the quantities of metals that would be added by this process. Unless the Basin F fluid contains metallic elements hitherto undetected, the impact of incorporation on the soil characteristics appears to be very small.

TABLE 2. AVERAGE, RANGE OF AND ADDED CONCENTRATIONS  
OF METALLIC ELEMENTS IN SOIL, (2,13)PPM

<u>Element</u>	<u>Average</u>	<u>Range</u>	<u>Added by Soil Incorporation</u>
AS	6	0.1-40	0.04
CU	20	2-100	29
Hg	0.03	0.01-0.3	0.001
Mg	-	-	1.5
Cd	0.06	0.01-0.7	1.7*
Cr	100	5-3000	0.004*
Pb	10	2-200	1.7*
Ni	40	10-1000	0.22
Zn	50	10-300	0.05

\*From AEHA 1973 report of unknown validity.

The principal problem associated with land cultivation of Basin F involves uncertainties in the fate of certain organic constituents. Aldrin and Dieldrin, which are present in significant quantities, have been shown to be very persistent in soils (11, 14). However, the concentrations as applied, shown in Table 3, may not present a significant impact.

TABLE 3. CONCENTRATIONS OF SOIL-INCORPORATED ORGANIC COMPOUNDS UPON INITIAL APPLICATION, PPB

Aldrin	8.2	DIMP	680
Dieldrin	1.8	DCPD	<0.4
Endrin	0.8	Sulfoxides	240
Dithiane	~ 3	Sulfones	1800
TOC	$9 \times 10^5$	COD	$1 \times 10^6$

Since organophosphates are amenable to treatment by biological systems, the low quantities of these materials in the soil matrix should be decomposed rapidly. The relatively high nitrogen and total phosphorus levels of the Basin F fluid should serve as added nutrients to the RMA soil structure.

Several pathways by which escape of toxic components from the RMA site could occur must be considered:

- Windblown contamination. This factor may not be of great significance since the levels of surface contamination would be small.
- Evaporation of organic constituents upon initial application and prior to mixing with the soil. This problem may be reduced by controlling the rate of application, or by subsurface injection. Over a three-year period, the Basin F contents need only be applied at a rate on the order of 50,000 gallons per day.
- Leaching of contaminants into groundwater and surface water runoff. Both problems are minimized by the low annual rainfall and can be further reduced by judicious selection of application dates. Biodegradation, of course, reduces the problem in time.

- Effect on higher life forms, including pathways to humans. The most probable means of the latter would be in contaminated ruminant animals through effects on vegetation. If necessary, the area could be fenced to preclude such possibilities.
- Fugitive emissions during land cultivation.

By way of the screening criteria, none of these pose insurmountable technical barriers to soil incorporation, at least in a qualitative sense<sup>(15)</sup>. However, there is a very real sociopolitical problem associated with the technique, and a great deal of effort would likely be required to establishing a convincing argument for its use. The method was eliminated from competition, then, primarily on the basis of anticipated "major permit problems" and associated regulatory issues.

### Physical Treatment

In general, reduction in the volume of liquid wastes is most easily accomplished by one of a variety of physical treatment methods. Processes exist which can result in removal of water in gaseous, liquid or solid form, although many were found to be inapplicable to Basin F contents. Discussion of the most widely known techniques follows.<sup>(16)</sup>

#### Steam Distillation

Steam distillation is a proven physical process for removal of water-immiscible, volatile compounds from waste streams. For immiscible liquids, each component exerts an independent vapor pressure, and the boiling temperature (when the sum of vapor pressures equals ambient barometric pressure) is reduced. Owing to the fact that a large number of both organic and inorganic compounds in Basin F are soluble and/or nonvolatile, this process would not result in sufficient cleanup of the waste liquid to be considered further.

### Electrodialysis

The basic principle of electrophoresis is separation of an aqueous electrolyte solution by an applied electrical field into two streams: an enriched stream which is more concentrated in electrolyte than the original, and a depleted stream. Success depends on special membranes such as ion exchange resins which permit passage of only anions or cations. This technique is not considered to be directly applicable to Basin F fluid for the following reasons:

- (1) Filtering to remove suspended matter is necessary to prevent clogging of the membrane. Resistant dispersions which have been observed in Basin F<sup>(1)</sup> would make removal a difficult process.
- (2) Chemical pretreatment would be necessary to oxidize reducing species that destroy the membrane. The requirements for and consequences of this process are unknown.
- (3) The high concentration of organic wastes would most probably result in membrane fouling.
- (4) The method does not remove or concentrate organic materials.

### Reverse Osmosis

This process is based upon the fact that water will flow through a semipermeable membrane away from an ionic solution if a pressure greater than the osmotic pressure of the solution is applied. The water flux will continue until the osmotic pressure of the brine is equal to the applied pressure. Reverse osmosis is not considered technically feasible in the present case because the osmotic pressure of the waste would exceed current state-of-the-art<sup>(16,17)</sup> for membrane strength (~1000 psi). This corresponds to 30,000-50,000 PPM total dissolved solids expressed as sodium chloride. The osmotic pressure of a 20% NaCl solution, which more nearly approximates the situation, is greater than 14,000 kPa (2000 psi).



### Ultrafiltration

This process is similar to reverse osmosis except that many ionic compounds will migrate through the membrane along with water, leaving high molecular weight impurities in the original stream. No volume reduction occurs directly, although separate subsequent treatment of the inorganic and organic solutions would be facilitated. For example, the inorganic stream might be evaporated or landfarmed, and the organic phase could be incinerated or treated in a biological reactor. This need for treatment adds to both R&D requirements and cost. The technology of ultrafiltration is not considered sufficiently advanced to evaluate application to Basin F without considerable further study.

### Extraction

Solvent extraction is based on the preferential distribution of solute from a liquid aqueous stream into a second liquid phase. For Basin F considerations, these processes do not address the objective of the present study, i.e., volume reduction, even though certain constituents could be removed by this technique. Extraction will not be considered further except as a secondary process to minimize the emission of objectionable compounds. A previous study<sup>(18)</sup> indicates that even then the process may be difficult due to formation of stable emulsions.

### Encapsulation and Storage

Deep Well Disposal. The U.S. Army Corps of Engineers has studied the feasibility of tank farms for temporary storage of fluid while Basin F could be repaired.<sup>(5)</sup> The idea was dismissed primarily due to an exorbitant construction cost and the time required for implementation. Drumming, encapsulation, tank storage or construction of another basin are not considered here primarily because these solutions do not solve the problem of reducing the volume of wastes. Similarly, deep well disposal is eliminated owing to uncertainties in application<sup>(2)</sup> and problems encountered in prior attempts.<sup>(1)</sup>

### Freeze Crystallization<sup>(19)</sup>

A solution may be fractionated based upon the differences in component concentrations between solid and liquid phases that are in equilibrium. For water solutions, formation of ice tends to exclude solutes from the crystal structure, i.e., the ice formed is relatively pure water. The process enjoys economies based upon both the single-stage purity (90-99%) and the low heat of fusion of water when compared with liquid-vapor separations. Freeze separation is a relatively new process, with commercial development dating from the early 1950's. However, the direct potential applicability to Basin F and the possibility of combining the technique with several other disposal methods make this process worthy of extended evaluation.

### Activated Carbon and Resin Adsorption Processes

Activated carbon has gained wide acceptance for removing pollutants from waste streams,<sup>(20)</sup> since it absorbs a great variety of organics, including non-biodegradables, as well as hexavalent chromium, mercury and many organometallic species.<sup>(21)</sup> Similarly, both carbon and synthetic resins have the ability to extract chlorinated pesticides and other toxic compounds from solution.<sup>(22)</sup> However, adsorption processes have been applied primarily for treatment of dilute wastewaters, i.e., solutions with less than about 0.1% by weight of active ingredients. Neither of the methods have been demonstrated on a large scale for removal of materials from concentrated waste streams. For the Basin F case, it is apparent that a wide variety of constituents in moderate to high concentrations would be adsorbed on the medium and the activated carbon would be rapidly depleted. Also, regeneration results in solutions of the adsorbed species in secondary media, thus not effectively reducing the volume of wastes as required. Adsorption processes are not considered applicable for treatment of Basin F for the purposes of this study.

### Clay Absorption (Sponge) Concept

A concept has been proposed for immobilizing the contents of Basin F by use of dry clay soil to absorb the liquids. Sufficient indigenous clay soil would be excavated, air dried and filled into the basin to allow absorption of the contents without exceeding the specific retention of the clay.

Calculations have shown<sup>(37)</sup> that filling the basin with  $1.2 \times 10^6$  cubic yards of clay with a residual moisture capacity of 30 percent resulting in a fill with 50 percent liquid content, would be required. There are several problems and unknown areas related to application of this concept upon which the feasibility depends:

- Characteristics of readily available subsurface clay soils at RMA are not well known, including plasticity index, drying and specific retention properties. From several boring profiles near Basin F,<sup>(3)</sup> clay soils with potentially desirable properties occur at depths of from 10 to 20 feet below the surface, in thickness of from 5 to 10 feet. Assuming average values for these quantities, removal of  $1.2 \times 10^6$  cubic yards would require excavation of at least  $2.4 \times 10^6$  yd<sup>3</sup> of topsoils, removal of the clay layer over a  $4.3 \times 10^6$  ft<sup>2</sup> (55 acre) plot, replacement of the original overburden and contouring of the resulting depression. The boring profiles show liquid limits for the clay layer of from 30 to 50 percent, plastic limits on the order of 15 percent, and a natural water content of 10-20 percent. It is difficult to predict how this soil would function as a drying agent, since the degradation on air drying and pulverization prior to filling the basin is not known.
- A great deal of handling would be required during the operation. Assume that the material would be dried in 400 feet long wind-rows that are 2 foot high by 2 feet breadth, with an interstitial spacing of three feet;  $1.2 \times 10^6$  yd<sup>3</sup> would then require spreading the material over a 27-acre area, even if the same drying area were used 20 times. The rows would have to be

arranged so as to promote surface runoff during periods of rain. Since most of the annual 15 inch of rain occurs in the summertime, turning of the windrows should be accomplished to promote rapid drying.

- The process of filling in the lake with the dry soil may be tedious. The high sodium content of the Basin F fluid would encourage dispersion of the clays<sup>(38)</sup> and discourage consolidation. Thus it may be difficult to compact the fill sufficiently to permit using previously filled areas as a roadbed for dumping operations. The use of other filling techniques would increase the costs of the operation.
- The hazardous substances present in Basin F could be readily leached from the saturated clay structure by simple displacement. If the fill is permitted to dry out, the cracks that form will allow percolation of surface water and result in a hydrostatic head on the bottom of the basin. Freezing and thawing would also tend to produce the same effect. An increase in subsurface contamination rates could thus occur.
- The effect of the organic constituents of Basin F on the plastic, cohesive and absorptive properties of the clay fill cannot be readily predicted. It is suspected that adsorption of the organic molecules, most species of which are hydrophilic in nature, would tend to reduce the specific retention of the soil by affecting the matric potential due to both capillarity and adsorption. The organics thus could act also as dispersion agents and inhibit consolidation of the fill. As noted above, the high sodium content also could produce the same effect.
- The method does not effectively reduce the volume of liquid wastes in Basin F. It has been suggested that evaporation be allowed from the saturated fill prior to capping; however, this process is controlled by capillary transport of water to the surface and occurs at a much slower rate than evaporation of surface water. It would thus be preferable to allow evaporation to the point desired prior to filling in the basin.

There are too many technical uncertainties at this time to recommend the method for adoption as a singular treatment process. It would appear that the concept at least has direct application as a "fixation" process for the last remaining vestiges of the lagoon following removal of most of the liquid. As a result, studies should be conducted to determine the capacity and physical properties of local clays that are mixed with the Basin F fluid. The study should also encompass variations as the liquid is concentrated by evaporation.

### Incineration

Incineration is an engineered disposal process that uses thermal decomposition via oxidation to convert a waste to a less bulky, toxic or noxious material. Under appropriate conditions, effluents consist primarily of carbon dioxide, water and ash with potential environmental pollutants containing sulfur, nitrogen, halogens and heavy metals. Secondary treatment may be required to remove the undesirable components from waste streams of the incineration process.

The combustibility of the waste is an important factor in determining applicability, and is characterized by flammability limits, flash point, and ignition temperature. Consequently, direct incineration of Basin F fluid is not considered feasible due to the high water (~80%) and inorganic salt (~17%) content. The various processes may be applicable after considerable concentration of the lagoon or to dispose of the organic effluent from an evaporation process. There are several types of incinerators in use to dispose of wastes,<sup>(23)</sup> the most significant of which are discussed below.

#### Multiple-Hearth Furnace<sup>(11)</sup>

This incinerator consists of a refractory-lined circular steel shell with vertically arranged hearths. Wastes fall through the top hearth drop holes and then successively through ports in each hearth. Combustion

having occurred incrementally in each stage, ash collects on the floor of the lower hearth; residence time may be up to several hours. Although liquid and gaseous wastes may be injected into the furnace through nozzles, the multiple-hearth design is best suited for solid wastes and sludges.<sup>(23)</sup> For Basin F application, other problems that preclude use of this design include buildup of refractory clinkers and scale from the salts content and volatilization/incomplete combustion of chlorohydrocarbons in the relatively cool ( $<600^{\circ}\text{C}$ ) upper stages. A critical factor is that multiple-hearth designs are not intended for intermittent operation, and commercial units are sized for very high throughputs.<sup>(24)</sup> The use of this concept for disposal of organics separated from Basin F fluid is thus not recommended.

#### Fluidized Bed

These units consist of a refractory-lined vessel containing an inert granular material through which air is blown to create a pseudo-fluid, turbulent reaction substrate. The bed is preheated by burners located within the chamber, and liquid waste enters the bed through nozzles located either above or within the bed. The primary disadvantages of the fluidized bed concern ash fusion of inorganic-laden materials which destroys the bed characteristics, removal of this and other residual material from the medium, and few examples of large-scale systems. Problems have occurred with feed equipment and temperature controls.<sup>(24)</sup> None of these problems seem to be insurmountable with proper design and operation. Fluidized-bed combustion is considered a potential means for disposing of essentially pure organics obtained from Basin F fluid, since none of the screening criteria are prohibitive.

#### Rotary Kiln

The rotary kiln is a cylindrical, horizontal, refractory-lined shell which is mounted at a slight incline. Rotation of the shell causes mixing of the waste with combustion air, thus improving thermal efficiency.

Combustion temperatures can be varied up to the 1600 °C range. Residence times vary from several seconds to hours; liquid wastes require the shorter dwell times. Rotary kilns are widely used in Europe <sup>(39)</sup> for mixed waste incineration and heat recovery, and recently have received increased attention in this country to incinerate captive industrial wastes <sup>(11)</sup> and as part of commercial disposal facilities. Portable units are currently being marketed than can burn up to 4 tons/hour. The basic feedstock for which rotary kilns are designed is solid or mixed wastes, and for application to Basin F wastes were not considered further in comparison with other incineration methods.

#### Microwave Plasma

This technique, which makes use of high power microwave radiation to decompose waste materials, is insufficiently developed to be evaluated against the known characteristics of Basin F fluids. Potential problems include high cost and power requirements. Uncertain product formation, leading to toxic or obnoxious effluents is a phenomenon that would require extensive research.

#### Photolysis

The photochemical oxidation of Basin F fluid is considered to be too marginal in meeting the objectives, regulatory requirements, emission limitations, or cost limitations to be considered further. The application of UV photolysis in conjunction with ozonolysis is discussed elsewhere in this report.

#### Molten Salt Incinerators

These units would be inappropriate for Basin F fluid disposal due to high concentrations of salts and residual water content. Also, only recently has the technique reached pilot-plant and demonstration scale, <sup>(23)</sup> making detailed evaluation difficult.

### Pyrolytic (air-starved) Incineration

In this method, waste organic materials are distilled or vaporized to form combustible gases. These gases are partially burned within the furnace and by use of external combustion chambers. Owing to the low calorific content of Basin F fluid or probable evaporation condensates and to the uncertainty in destruction of toxics, this method is not recommended.

### Liquid Incinerators

Incinerators designed for liquid waste disposal, including vortex burners, may have application in disposal of organic condensates from evaporation processes. Due to ash fusion and/or clogging problems at the atomizer, Basin F fluid in any concentration could not be incinerated directly. Both types can operate at combustion temperatures up to 1600°C, with consequent decomposition of difficult moieties such as chlorohydrocarbons. Of the various incineration methods discussed, Fluidized-Bed combustion and generic-form liquid waste burners were considered to be most applicable in the present case.

### Emissions Control

A very real problem associated with any incineration system is the control of emissions. Both gaseous and solid effluents can pose severe environmental problems, particularly for complex feed streams, and elaborate, costly posttreatment systems are often necessary. For any incineration process, it is proposed that emissions of both types take advantage of the existence and planned fate of Basin F; i.e., ash from combustion can be directly deposited in the basin and gaseous emissions can be scrubbed by exhaust below the surface. An additional incentive for this treatment is enhanced evaporation of the fluid contents by the hot exhaust gases. Such factors are described in greater detail in the section of this report under Evaporation methods.



### Chemical Treatment

Many chemical approaches have been taken to detoxify or destroy hazardous materials and wastes. Some techniques involve rather simple treatments in solution, whereas others are quite more complex and require elaborately engineered systems. Some methods are capable of completely destroying specific compounds, whereas other materials may be only partially decomposed or may yield products that are just as objectionable as the original entity. The probability of finding a simple, universal chemical reagent to destroy or degrade the pollutants in systems such as Basin F appears to be very small, and in general incineration has been found to be superior to chemical treatment as a general degradative method.<sup>(11)</sup> Also, many of the more innovative chemical methods are relatively unproven on a large scale, making evaluation for this current study difficult. Those techniques which were considered are included in the discussion below.

### Chemical Fixation

Chemical fixation involves the mixing of various chemicals such as limestone, fly ash, or other proprietary materials with the wastes. The product of these processes has improved physical properties in that it acts more or less like a solid, and the leaching properties upon landfilling are controlled. Fixation can produce cement-like aggregate materials, mineral-like silicate matrices, or organic polymeric solids. Table 4 shows typical processes that are marketed commercially, primarily for treatment of industrial wastes.<sup>(24)</sup>

Fixation is most appropriate for solid wastes and sludges where little dewatering is required. Other factors that must be considered are:

- The proprietary nature of most processes, making objective evaluation difficult without experimental evidence, and making costs more-or-less non-competitive.
- Volume to be treated.
- Characteristics of the product with respect to ultimate disposal. For example, for filling and capping of the basin the material must have reasonable compression properties and be appropriate for freeze-thaw cycles.

TABLE 4. TYPICAL CHEMICAL FIXATION PROCESSES

Vendor	Process	Additives
Dravo Corporation	Synearth <sup>*</sup>	Calcilox, <sup>*</sup> Thiosorbic <sup>*</sup> lime
Chemfix, Inc.	Chemfix <sup>*</sup>	Portland cement Sodium silicate Other setting agents
TRW, Systems Group	-	1,2 - Polybutadiene
(Several Companies)	Fly ash-limestone	Fly Ash Limestone
Ecology Products <sup>(25)</sup>	-	Lime Other Materials

\*Registered Trademarks

- The degree to which the fixed product must resist leaching; tests for this parameter are not well-formulated.
- Reactivity and suitability of the waste with the fixation chemicals.

In view of these uncertainties, the technical feasibility of chemical fixation for suitable solidification of Basin F cannot be definitively evaluated. It is strongly suspected that the technique would be applicable only after removal of most of the water, in which case the treatment involves ultimate disposal rather than the subject of this report.

#### Hydrolysis and Other Chemical Treatment

No information on simple chemical treatment methods for waste streams as complex as Basin F were found. The technology is simple and available, however, and some discussion on the subject is essential.

Alkaline hydrolysis has been shown to be a feasible method, on a research scale, for destruction of certain pesticides.<sup>(11)</sup> However,

residual toxicity and uncertain hydrolysis products would be expected for complex mixtures. Raising the pH of Basin F fluid could result in precipitation of some metals, and will result in liberation of heat. These points may be deleterious or advantageous, depending on details of the process.

Chemical treatment by addition of liquid or solid oxidizing agents does not appear feasible, at least in comparison with the ozonolysis process discussed below. Very limited data using a variety of pesticides and other compounds similar to Basin F constituents indicate incomplete degradation, formation of other toxic agents, and/or no significant reaction in many cases. Whereas it is probable that extended chemical treatment could ultimately degrade or eliminate all objectionable components of Basin F, a large amount of research beginning at the test tube stage would be required. This factor and the anticipated ultimate costs for multiple chemical treatment eliminates the concept from competitive evaluation.

#### Catalytic Dechlorination and Reductive Degradation (11)

These methods, which depend on metal catalysis for removal of chlorine or addition of hydrogen, may hold promise for destruction of certain classes of toxic organic chemicals. However, the processes are unproven on a large scale and currently suffer from several disadvantages that eliminate consideration:

- Catalyst poisoning is likely using Basin F fluid.
- Residual toxicity of products.
- Incomplete data for cost/schedule evaluations.

UV/Ozonation

This method of detoxifying hazardous chemicals in solution is currently under development. The technique involves rather simple equipment: a reactor vessel, ozone generator, means for diffusing the gas, a mixer, and a high pressure mercury lamp or other source of intense UV light. Materials that have been shown to be reduced to tolerable levels include several classes of pesticides, heavy metal cyanides, and explosives residues.<sup>(11)</sup> The U.S. Army Corps of Engineers has reported on bench-scale testing of UV/ozone as a means for treatment of RMA groundwater.<sup>(26)</sup> Battelle has chosen the results of that study to evaluate potential applications for treatment of Basin F, since no large-scale demonstration results were otherwise found. Several factors were extrapolated to make a comparison:

- A comparison of the inlet stream from reference (26) and Basin F fluid is shown in Table 5. It is observed that the two systems differ considerably in complexity and constituency. Comparison of several of the entries indicate an approximate 100-fold dilution of the primary Basin F waste in the groundwater.
- To treat  $5 \times 10^7$  liters ( $13 \times 10^6$  gallons) of Basin F waste per year would require processing  $1.4 \times 10^5$  l/day. For two 8-hour shifts, this equates to  $8.6 \times 10^3$  l/hour. Since moderately effective (80%) removal of TOC in the bench studies required a residence time of 2 hours, the full-scale vessel would be required to have a capacity of  $1.7 \times 10^4$  liters, an 815-fold scale-up of the 21 liter bench model from this factor alone. (Incidentally, there is only scant evidence that 80% TOC removal is sufficient treatment of the waste; further degradation may be required).
- Combining the two factors above, an  $815 \times 100$  or roughly 80,000-fold scale-up of the bench tests would be required. (This assumes a first order reaction with respect to TOC concentration, as the removal curves in reference (26) indicate).

TABLE 5. BASIN F <sup>(2)</sup> and RMA GROUNDWATER <sup>(26)</sup> ANALYSES, ppb

Contaminant	Basin F	Groundwater
Aldrin	205	<2
Dieldrin	44	2/4.5
DCPD	10	80/800
DIMP	17	3600/410
Sulfoxide	6000	10/53
Sulfone	40,000	10/45
Endrin	21	2/8.6
Total P	$2 \times 10^6$	1000/1800
TOC	$2.2 \times 10^7$	$1 \times 10^4 - 2 \times 10^4$
Sulfate	$2.4 \times 10^7$	$2 \times 10^5 - 8 \times 10^5$
Chloride	$5.2 \times 10^7$	$3 \times 10^5 - 6 \times 10^5$
COD	$2.5 \times 10^7$	$2.4 \times 10^4$
Total Solids	$1.6 \times 10^8$	$1.2 \times 10^6 - 2.4 \times 10^6$
Sodium	$3.6 \times 10^7$	$2.4 \times 10^5 - 5 \times 10^5$
Copper	$7.3 \times 10^5$	1
Mercury	27	0.2

- There is insufficient data to determine the photon efficiency of the reaction, although there does not appear to be a strong dependence upon the intensity of UV light. We assume that a radiation density of 100w/21l, or about 5 watts/liter, is sufficient. Similarly, an ozone concentration of 2% by weight will be assumed. These data, when applied to the Basin F waste and full-scale reactor would require an ozone flow rate of 170 kg/hr, and a total UV intensity of 85 kw. Over the three-year life, this would amount to  $3 \times 10^6$  kg ( $1.4 \times 10^9$  l @STP) of ozone and  $1.5 \times 10^6$  kw-hours of UV energy. Aside from technical difficulties of fabricating a suitable reactor, the operating costs would be astronomical. UV/Ozone methods are thus not considered sufficiently developed for treatment prior to disposal of Basin F fluid. If further work is to be done, it is strongly suggested that the reaction progress be monitored by measurements of actual species present rather than TOC or COD. As a further disadvantage, products and intermediates formed in the ozonolysis of organic toxins often are more toxic than the starting material. (22)

#### Wet Air Oxidation

The basis for this process is that any organic moiety can be oxidized by air/oxygen and water under conditions of sufficiently high temperature and pressure. At temperatures up to 350°C and pressures ranging upward to ~17000kPa (2500 psi), organics may be oxidized to CO<sub>2</sub> and water; sulfur, nitrogen and phosphorus should be found in high oxidation states; and heavy metals may be precipitated as sulfates, phosphates, oxides or hydroxides. These potentialities indicate the possibility for significant cleanup of the Basin F wastes.

In contrast to other oxidation methods, and except for inexpensive air and water, the primary parameters of a wet air oxidation process are intensive variables such as temperature and pressure. Thermal energy requirements are supported by the fact that the reactions are exothermic, and

the mechanical energy input to maintain a given pressure is essentially invariant. These factors positively affect the operating economics of the situation, whereas the severe requirements for reactor and plumbing design tend to make the process capital investment-intensive.

The process dynamics that have been presented show a fast, possibly multiple-order initial reaction, followed by a much slower reaction that is approximately first order in concentration of reacting species. It is possible that the later phases may be controlled by diffusion or other factors that limit reaction rates; more detailed studies would be required to determine precise reactivity rates and retention times. Conversations with RMA personnel indicated that a 98% reduction in TOC with retention times of one hour would be possible. It is felt that treatment using wet air oxidation would result in a product that is suitable for subsequent biological or adsorption treatment prior to discharge. The process is considered worthy of more in-depth study.

### Evaporation

Under the general area of evaporation, processes dealing with the vaporization of a liquid from a solution or slurry for separation of a liquid from a dissolved or suspended solid or liquid are considered. The process and equipment are similar to the boilers and stills of distillation, except that in the latter case the separated components are condensed and collected.

Evaporators differ primarily in the manner in which heat is applied and in attempts to increase both thermal efficiency and mass-transfer rates. Practically every chemical industry uses some sort of evaporation system, so the technology is well-developed. Complexity can range from solar evaporation ponds to sophisticated distillation/fractionation unit operations. Applications here will be considered only as a primary process for volume reduction of Basin F wastes.

A recent report provides some data on evaporation characteristics of Basin F waste.<sup>(27)</sup> Significant findings or deductions from the data are:

- Essentially all distilled organics can be condensed at ambient water temperatures, assumed to be 10° - 25° C.
- No significant fraction distills until a temperature of 105° - 107° C is reached, with a vapor temperature of 100° C; this indicates that water is the principal distillate. The bulk of liquid boils at 112-115°C, with corresponding total solids content of 30-75%. A saturated 28% NaCl solution would boil at approximately 105°C.
- At around 120°C and 80% solids, there was evidence of decomposition, sublimation, or distillation of hygroscopic vapors.

The data indicate that water is the principal low-temperature distillate. Unfortunately, no analytical, density or other measurements were made on the distillate to prove the case. The question of the organics composition that comprises 2-3 percent of the fluid remains unanswered, except that apparently very small percentages of light organics (b.p.

<100°C) were found. (Details of sampling and sample handling prior to these experiments are unknown, so it cannot be determined whether prior volatilization of the light organics had occurred.



The primary problems concerned with open-air evaporation of the basin, and means for enhancement, are the odor and other aesthetic qualities of the process. A limitation to increased evaporation has been put forth as that of the full basin. Since about two-thirds of the 90-acre basin is covered with water, an increase in evaporation rate of 50 percent above the present case has been assumed permissible. As an approximation, this may be accomplished by:

- (1) Raising the mean temperature of the body by approximately 10°C.
- (2) Increasing the evaporation surface area by 50 percent.
- (3) Since rainfall is approximately 50 percent of estimated evaporation rate, elimination of precipitation influx.
- (4) Forced evaporation at the rate of about 110 liters per minute (30 gpm). This would require about ton of coal or 4 barrels of oil per hour.
- (5) Some combination of the above factors.

RMA records were obtained showing data for monthly influx from the plant area, amounting to  $35.6 \times 10^6$  gal during the 7-month period from February to August 1979, which equates to an influx of  $61 \times 10^6$  gal/year or 167,000 gal/hour. This does not seem possible; it is apparent that the "input from plants" data entry represents the difference between measured precipitation amount, a calculated evaporation rate and the volume change obtained from elevation measurements. Orally, a figure of 50,000 gpd influx was obtained from Army personnel, whereas observations indicated a flow rate of <10 gpm or about 15,000 gpd as a maximum. This latter figure will be used in subsequent calculations; i.e., an annual influx of  $5.7 \times 10^6$  gallons is assumed.

#### Reduced Rainfall Area and Plant Influx

Some indication of the importance of the first factor can be obtained by volume and rainfall observations over the past year. From February 1979 to January 1980, the volume decreased by  $26 \times 10^6$  gal, while the total precipitation amounted to 15.8 inches, or about  $26 \times 10^6$  gallons. If the (average) 25 percent dry area had been excluded

from precipitation input, the present volume would have been reduced by  $6.5 \times 10^6$  gal. In energy terms, this is equivalent to  $5.4 \times 10^{10}$  Btu, or  $1.6 \times 10^7$  kw-hr. Using the cheapest available energy source, i.e., Western coal at \$20 per ton and 70 percent efficiency, the dollar equivalent is \$60,000. For years to come, with increased percentages of dry area, the potential savings are even higher.

Since the presently planned ultimate fate of the reservoir is to fill and cap with clay, it would appear judicious to perform this operation periodically in such a manner that the evaporation and precipitation influx areas are roughly equal.

A similar rate of volume decrease will be obtained upon elimination of the current influx from the plant activities at RMA. The combination of these two factors represents one of the most obvious, least costly, and most easily implemented method for enhancing the effective evaporation rate of Basin F.

#### Simple Evaporators

Calculations show that a very simple evaporator design can be used to reduce the volume of Basin F. The concept is considered applicable and was studied in greater detail.

#### Multiple Effect Evaporators

Of the types of typical commercial evaporators available, including horizontal and vertical tubes, wiped film, cyclone flue, etc., a multiple-effect evaporator using falling film techniques appears to be most feasible. The Carver-Greenfield process is an example of this type, with an additional feature of oil addition to improve the efficiency. This oil component, however, may pose severe problems due to formation of stable emulsions and/or dissolution in the fluid, and in extraction of dissolved organics in subsequent processing. No information was obtained relative to use of this process for evaporating highly saline waters; fluid heat capacity, thermal conductivity, composition and

characteristics of residue formed on evaporation are also unknowns. Evaporators of this type were considered potentially feasible for use at present, but with increased uncertainty of operation as the liquor concentrates. Technical feasibility is thus too uncertain for consideration at this time.

#### Submerged Combustion

In this technique an oil-fired or gas burner is immersed in the solution to be evaporated. Since scale formation is eliminated<sup>(16,28)</sup>, these evaporators are well-suited to handling scale-producing or highly corrosive solutions. Furthermore, the economics of energy utilization are greatly improved since heat transfer is about 92 percent efficient. (The efficiency of steam boilers is approximately 80 percent). However, the combustion gases can decompose wastes at the high temperatures involved and the potentially toxic products could be evolved into the atmosphere. In the case of Basin F, air pollution regulatory requirements eliminate this method from competition. Expected contaminants include chlorine, chlorine oxides, and light organics as well as the usual gaseous products of combustion.

#### Evaporation Ponds

Additional evaporation ponds can be constructed, into which the Basin F fluid would be admitted. To minimize the potential for additional groundwater contamination, these ponds would need to be specifically designed with liners to preclude that possibility. The problem of regulatory impact may be of significance here. The question is whether new evaporation ponds under the RCRA guidelines would constitute a new hazardous waste impoundment. This contrasts with the present Basin F case, which represents a "Grandfather" site and for which time (approx. 5 years) is permitted to attain compliance. Regardless, evaporation ponds imply an increased area over which the wastes are spread, and that can be provided within the basin itself without additional construction. The regulatory implications and political sensitivity of these issues lead to discard of this method, in comparison with use of dry portions of the existing basin.

### Surface Area Enhancement

Two methods for increasing the surface area of the liquid while maintaining all wastes (except volatiles) within the basin proper are possible. The currently conceived notion of pumping liquid onto the dry areas definitely appears feasible, all evaluation factors considered. The only energy requirements involve pumping the fluid through a few feet of head. The evaporation rate at present could be increased by about 50 percent by this method. The major disadvantage lies in reduced efficiency as the volume becomes smaller: equilibrium with rainfall input will probably still occur, except that the lake will stabilize at a smaller volume, and problems with pumping will increase as the solid/liquid ratio increases. Whether these limitations will occur prior to sufficient concentration to permit direct landfilling and capping is unknown.

The second method of surface enhancement would make use of artificial or fabricated surfaces to increase the surface area, solar thermal efficiency and/or convection properties. Structural surfaces, e.g., black corrugated metal surfaces over which the liquid is allowed to trickle, would serve as an effective evaporation medium. The angle of tilt could be varied to match solar azimuth as the seasons change. A further refinement whereby the corrugated surfaces, in a horizontal mode, could be used to catch and divert rainwater is possible. These two features actually complement each other; in the summer months, when most rainfall occurs, the plates would be in a near-horizontal position anyway to maximize solar absorption.

Flat plate solar collectors that are reoriented about once per month will receive  $367 \text{ cal/cm}^2$  ( $1353 \text{ Btu/ft}^2$ ) per day<sup>(29)</sup>, on the average, in Denver. Assuming a nominal absorptivity of 0.9 and heat transfer efficiency of 0.8, a thin film of water on the collectors will be imparted with  $9.6 \times 10^4 \text{ cal/cm}^2$  per year. Since evaporation of  $5 \times 10^7$  liters ( $13 \times 10^6 \text{ gal}$ ) requires  $2.7 \times 10^{13}$  calories, an area of  $2.8 \times 10^8 \text{ cm}^2$  ( $3 \times 10^5 \text{ ft}^2$ ) would be required for a 50 percent increase in current evaporation rate of Basin F. Since the collectors can only be placed along the Northern edge (approx. 1000 ft. long) in order to prevent shading of the basin and reduced natural evaporation, an excessive height of 300 feet would be required for the collector system if the structure is built

within the confines of Basin F proper. On the other hand, 1500 (i.e., a finite number) of 20 feet x 10 feet collectors in an arrangement outside the basin would be required. The actual number will be reduced somewhat since the effective surface area for evaporation (including higher temperature) will have been increased by 15-25 percent, without adding to the area of precipitation input. The latter arrangement will require considerably more pump and plumbing hardware.

Flow rates to the collector farm will depend on the liquid film velocity across the plate, which can be used to control the temperature of the fluid and thus the degree of air pollution. As an order of magnitude estimate, for a plant flow velocity of 1 cm/sec., film thickness of 0.2 cm, and total plate area of  $2.8 \times 10^8 \text{ cm}^2$ , a flow rate of 17,400 gph is required. The advantages of enhanced surface areas is obvious, but in comparison with use of the dry lake portions ( $1.3 \times 10^6 \text{ ft}^2$ ) as a natural solar collector, this and any artificial solar collector surface cannot be justified from cost and potential environmental contamination standpoints.

#### Spraying and Aeration

Of several methods investigated in 1969 by the Bureau of Reclamation for increasing evaporation rates of brine ponds<sup>(30,31)</sup>, a spray system was shown to be one of the most effective and economical. Proper design provided enhancements of 17 to 60 percent while suppressing aerosols and other undesirable effects. Other than sociopolitical implications, a spray system would be recommended for application at Basin F.

An associated possibility for increasing the air-surface interface is to bubble air through the medium. A rough calculation was made of the air volume required to perform the task. Assuming that the bubbles under 1 atmosphere pressure equilibrate with water vapor to the same degree as the bulk surface, 50 percent enhanced evaporation requires a total bubble surface area of  $1.2 \times 10^9 \text{ cm}^2$  (30 acres).

The required volume of air, for bubbles of 0.01 cm radius, is  $4 \times 10^6 \text{ cm}^3$  ( $140 \text{ ft}^3$ ). (The volume required scales directly with the radius of the bubble). If the residence time of the bubbles is 10 seconds, an air flow rate of 840 cfm would be required. Based on a pressure differential of 5 psig, the  $\Delta PV$  product energy use rate is  $4200 \text{ psi ft}^3/\text{min.}$ ,  $6.0 \times 10^5 \text{ ft.lbs/min}$  or about 18 hp. For a combined efficiency of 30 percent, the energy requirement is 60 hp, or 45 kilowatts. Over three years of continuous use, this process would consume  $1.2 \times 10^6 \text{ kw-hrs}$ , at a cost on the order of \$40,000. The method thus appear attractive.

Further calculations based on transport properties of gas-in-liquid dispersions, however, reduced enthusiasm for the method. Gas-in-liquid dispersions have been treated both theoretically and practically.<sup>(28)</sup> For the purposes of this study, some general characteristics will be presented rather than a general treatment. The objective is to evaluate the feasibility of the method for removing liquid (water) from Basin F.

Data obtained from reference (28) was used to determine the degree to which the method could effectively increase evaporation from the liquid in Basin F. A simple scenario was developed whereby the lake itself was used as the liquid column, gas dispersion was accomplished using porous septa placed near the bottom of the deeper portions, and air flow was introduced via piping from compressors; air heaters were considered to increase the efficiency. Porous media spargers may be fabricated of materials such as stainless steel, plastic, carbon, silica and alumina in a variety of sizes. Pressure differential depends on pore size and flow rates, but the following were taken as typical conditions:

Water column: 8 feet

Pressure drop (incl. liquid head): 126" water = 5 psi

Air Flow:  $10 \text{ ft}^3/(\text{min})(\text{sq.ft.})$

Bubble rise velocity: 0.4 ft/sec

Bubble diameter: 1 mm

Assuming that vapor equilibrium between gas and liquid is attained during the 20-second contact time, a water removal rate of only 170,000 gpy is possible using 400 sq.ft. of diffuser surface and an air flow of 4200 cubic feet per minute. This quantity is about two orders of magnitude below the assumed requirement of  $13 \times 10^6 \text{ gpy}$  removal. Unless the oxidation possible by aeration of the lagoon can be shown to supply a very large

benefit, this method is otherwise not considered feasible for volume reduction of Basin F.

#### Evapotranspiration

Biological methods for increasing evaporation rates have been studied and observed for some time.<sup>(30)</sup> Plants growing in aqueous media consume water during growth and enhance evaporation through transpiration. However, there is no evidence to indicate that flora of any order will grow in Basin F, and in fact the constituency almost certainly precludes further evaluation of these processes.

#### Solar Still

Solar energy may be used in an inexpensive and moderately efficient closed evaporation system. A body of water is covered at some height with an impermeable material that transmits sunlight. Vaporizing liquid that is heated by absorption of the solar energy will condense on the lower surface of the membrane, from which it is diverted to a collection vessel. The process is used extensively for evaporation of small quantities of water from saline solutions. For a large scale application such as Basin F, meaningful vaporization rates would require covering of a large area; thus supporting structures required for integrity against wind and weather and maintenance problems with the films prohibit use of the method. Also, the water that is condensed would likely contain trace quantities of hazardous organic materials and itself would pose a treatment and disposal problem.

### Summary of Screened Methods

A summary of major problem areas encountered in the various classes of treatment methods is shown in Table 6. The list of 53 methods that were considered at the onset of evaluation has been reduced to 5 and are summarized as follows:

- Biological Treatment - Only land cultivation is considered feasible for primary treatment of Basin F wastes, primarily due to the salt content of the liquid.
- Physical Treatment - Freeze concentration alone is considered feasible.
- Chemical Treatment - Wet Air Oxidation is considered to be the most directly applicable for treating the wastes for ultimate discharge; several unknown areas remain to be explored, however.
- Evaporation - Two methods appear feasible:
  - (1) Reduction in the degree to which influents contribute to the volume.
  - (2) Enhancement of the Basin evaporation rate by increasing the surface area of the fluid.
- Incineration - Incineration is considered to be applicable only toward disposal of a separated organic phase. Since none of the alternate techniques result in an organic waste stream, incineration is not considered further. The techniques other than incineration are considered in the following sections.

Discussion of these methods in terms of the evaluation criteria are provided in the sections to follow.



TABLE 6. PRIMARY TREATMENT PROBLEMS

<u>METHOD</u>	<u>PROBLEMS</u>
I. BIOLOGICAL TREATMENT	SALT CONTENT RESISTANT COMPOUNDS TOXIC METALS
II. PHYSICAL TREATMENT	HIGH CONCENTRATIONS INCOMPLETE TREATMENT COST
III. CHEMICAL TREATMENT	COMPOSITION COMPLEXITY R&D REQUIREMENTS SIZING & COST
IV. EVAPORATION	SCALING AND CORROSION AIR POLLUTION
V. INCINERATION	WATER CONTENT SALT CONTENT AIR POLLUTION

## Wet Air Oxidation

### Technical Feasibility

Wet Air Oxidation has been demonstrated on a bench scale to show promise as a treatment method for Basin F fluid.<sup>(42)</sup> Although neither the process parameters nor equipment design was optimized in that short program, a 90% reduction in TOC and a 50 percent decrease in total solids was observed. Up to 99% removal of TOC has been reported in data obtained from RMA personnel<sup>\*</sup> as a result of less than 60 minutes residence time in the reaction vessel. These results indicate a very real probability that the process, if studied in detail, could be used to reduce the level of organics in Basin F to a level that is tolerable, while at the same time removing heavy metals and many other inorganic species. The method thus appears to fit quite well the characteristics of Basin F; air pollution problems would be low, the energy requirements are modest, toxic materials are destroyed, the process is more efficient at high concentration, and the inorganic salts present do not present difficulties. In brief, the advantages of incineration are offered for this system that cannot support combustion and which is not amenable to simpler treatment.

Wet Air Oxidation systems are currently in use to process waste streams from dye, organic chemical, pesticide and herbicide, plastic and resin, pulp and paper, petrochemical, and steel industries. The technology, though relatively young, is considered sufficiently advanced to initiate pilot scale studies. Some Research and Development would be required; for example, the use of pure oxygen instead of air has proved economical for large throughputs of waste and should be investigated for this case. Other operating parameters such as temperature, pressure, catalytic effects, residence time, etc also need to be optimized, but pilot studies to define the conditions should be amenable to a 1-2 year development time frame.

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\* Lovin, C., private communication, March 1980

### Costs

Continuing development has gradually reduced the cost of Wet Air Oxidation processes and the exothermic nature of organics oxidation significantly reduces energy costs. At present, the process is capital-equipment costs intensive. For a system that would process 30-40 gpm (~50,000 gpd), an equipment costs of \$2M-\$3M is estimated, with annual operating costs on the order of \$300K. At these throughputs, and considering that natural evaporation also reduces the volume in the meantime, the fluid could be treated in 3-4 years.

### Regulatory Issues

Air pollution should not be a problem since those entities of greatest significance (organics, sulfur oxides, and nitrogen oxides) are oxidized to innocuous or nonvolatile species in the process. Depending on the condition of effluent, water pollution could present problems and further details on the products of the method would be required before definitive regulatory guidelines can be offered. If necessary, simple adsorption methods or solid incorporation can be used to provide final cleanup of the waste streams. Major permit problems are not anticipated, and the fact that this process results in destruction rather than just concentration of the hazardous materials should soften any political or regulatory stances.

### Research and Development Requirements

Pilot scale studies are needed to optimize operating conditions, as noted above. Since the method has been used with success in bench scale operations, the risk that findings will negate predictions of large-scale applicability is small. The major unknown is to what degree effluents from the process will require further treatment.

### Major Advantage

The primary advantage that this process offers is that the hazardous materials in Basin F would be destroyed at the same time that the liquid content is eliminated. Problems associated with ultimate fate of the reservoir, as definitized elsewhere in this report, are thus minimized. For this reason, Battelle urges continuing development of Wet Air Oxidation as a treatment method, even if some other volume reduction process proves more desirable.

### Simple Evaporation

#### Technical Feasibility

Over a normal range of ambient temperatures, the vapor pressure of water approximately doubles for every 10°C rise in temperature. Since the mean annual temperature of Basin F is about 10°C, the vaporization rate (including precipitation) can be increase by 50 percent (i.e.,  $13 \times 10^6$  gpy) by raising the mean temperature to 20°C (68°F). An estimate of the energy required to do this was made as follows:

- (a) Initial heating of  $84 \times 10^6$  gal from 10°C to 20°C requires  $3.3 \times 10^{12}$  calories.
- (b) Evaporation heat loss from  $13 \times 10^6$  gal is  $2.7 \times 10^{10}$  cal/year.
- (c) Conductive, radiative and convective losses are assumed to total  $3.3 \times 10^{12}$  cal/month.
- (d) Total heat required =  $(3.3 \times 10^{12}) 13 + 2.7 \times 10^{10}$   
 $= 4.3 \times 10^{13}$  calories/year =  $1.7 \times 10^{11}$  Btu/year.
- (e) At 50 percent efficiency, this would require 13,000 tons of coal per year, at a cost of about \$260,000.

A simple evaporator design was conceived in lieu of commercial systems for several reasons:

- (a) The equipment would be abandoned in place prior to filling the Basin; thus long life and a high degree of maintainability

are unnecessary; planned obsolescence at 3+1 years could be built into the design.

- (b) Deposition of residues on evaporator surfaces is certain; most commercial designs would make periodic or continuous cleaning difficult.
- (c) Current designs are intended to be used as a stand-alone unit process, rather than within a lake such as Basin F.
- (d) Recovery of neither distillate nor residue is desirable.
- (e) Simple designs could be fabricated quite inexpensively, although non-corroding materials probably will be required.
- (f) Most commercial units use steam as a heat source, rather than directly using combustion gases.
- (g) Installation cost can be reduced over that of present designs.

The concept here is to maintain efficient heat transfer by using flat surfaces that can be scraped continuously to remove deposits, to increase efficiency by exhaust of combustion gases below the surface, and to scrub the gases of atmospheric pollutants at the same time. This allows direct forced-air combustion of cheap high-sulfur coals as a heat source. Figure 4 shows a conceptual schematic of the process.

Actual boiling of the liquid is not envisioned in this process; rather, sufficient heat would be transferred to the lake to maintain a thermal profile sufficient to allow vaporization of 35,000 gallons per day without inordinate heat loss. A detailed analysis making use of thermal transport properties of the fluid (currently unknown), heat transfer rates, etc., would be necessary prior to actual design; the 13,000 tons of coal per year is probably a high estimate of fuel requirements. Elimination of boiling has two distinct effects:

- (a) The enhanced evaporation is less visible to surrounding communities, particularly in cold weather.
- (b) The potential for atmospheric pollution, other than

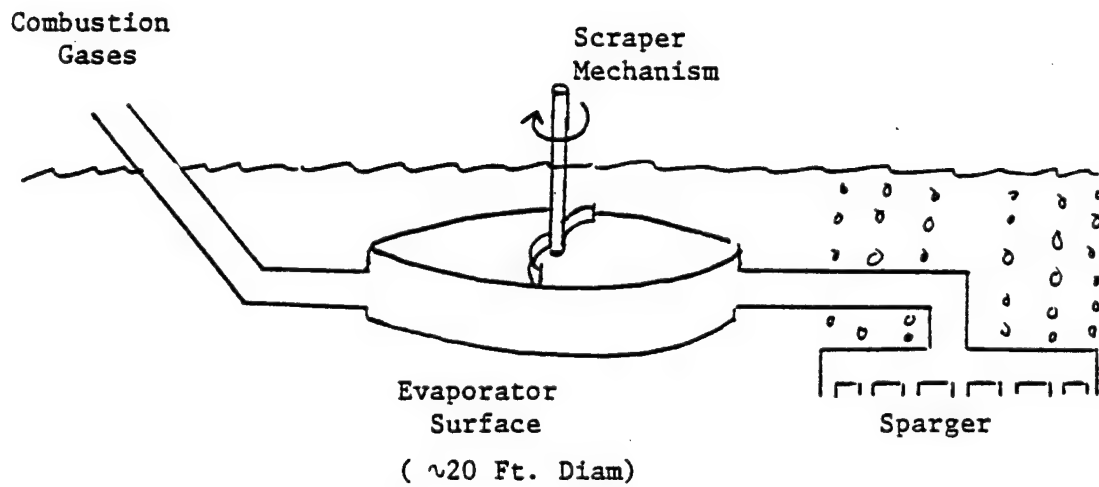
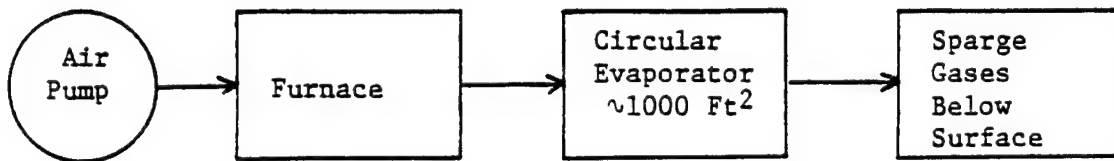


Figure 4. Simple Evaporator Concept

compounds that are currently being volatilized, is lessened, both by the lower temperatures employed and by reduced entrainment in vapor bubbles.

To further study this method, several data gaps need to be addressed, and feasibility of the method depends strongly on these unknowns:

- (a) Exact evaporation behavior of the wastes; vapor pressure as a function of temperature; chemical composition of volatile effluents.
- (b) Thermal and mass transport properties of the fluid; diffusivity, conductivity
- (c) Chemical composition of all major components of the waste, and an evaluation of their fate over time as a function of temperature.
- (d) Natural evaporation rate of Basin F, to properly size the evaporator design.

#### Costs

The capital cost will vary considerably depending on the design parameters of the furnace and evaporator. A ballpark figure of \$400,000 installed cost is estimated, with construction requiring 4-6 months. Operating costs, including fuel, should not exceed \$400K per year.

#### Regulatory Requirements

Air pollution permits may be required; depending on results of pilot studies, this may prove difficult. Design of the system would address near-zero discharge of Clean Air Act (NAAQS) contaminants, but emission of organics cannot be predicted. All nonvolatile materials would remain within Basin F and no regulatory problems beyond the current situation are envisioned. Noise pollution would be negligible.

### Adverse Effects and Potential Problems

During the winter a steam cloud will be visible to outsiders, and increased odor will likely result. Both of these factors, however, are controllable if a throttleable system is designed.

### Major Advantages

The process directly, and controllably, reduces the volume of Basin F. All contaminants except highly volatile organics are retained within the basin. The anticipated costs are reasonable. The process is recommended for further study and pilot operation.

### Freeze Concentration

#### Technical Feasibility

Freeze concentration has been proposed<sup>(33)</sup> as one of three processes (the others are distillation and reverse osmosis) capable of removing greater than 90 percent (95-99 percent in most cases) of suspended solids, BOD, COD, and total dissolved solids from wastewater. Units have been built in the 100,000 gallon per day size range,<sup>(19)</sup> whereas removal of  $13 \times 10^6$  gpy equates to 35,000 gallons per day as the requirement for Basin F removal rate. Risk is considerable, and depends upon the low temperature thermal characteristics of Basin F and the question as to whether the impurities trapped in the ice formed can be treated by a simple biological process; these considerations must be considered as data gaps, which may not be resolved within a year of pilot-scale effort.



### Schedule

Design of a process for application to Basin F will depend upon resolution of uncertainties to such an extent that it is difficult to estimate design and construction time; 1 (+1-0) years should be adequate. With natural evaporation, two years of operation would remove an additional  $26 \times 10^6$  gal of liquid from the basin.

### Costs

Capitalequipment and installation costs for a 35,000 gpd unit are estimated to be on the order of \$1.5M to \$4M, depending on the number of shifts in operation. Power costs (electricity) at \$0.03 per kwh would amount to \$150K-\$300K. Labor costs at 1 man per shift at \$18/hour would vary from \$50K to \$150K. Maintenance costs at 6 percent of capital investment amounts to \$90,000 to \$240,000 annually.

### Regulation and Permit Requirements

The resulting liquor after melting of the separated ice will contain concentrations of ions and organics that are difficult to predict. It is assumed that further treatment will be required prior to discharge in order to meet requirements of the Clean Water Act. It is not expected that permits will be required for the primary process, although OSHA regulations will apply.

### Adverse Effects and Anticipated Problems

Freezing, washing of the crystals, and melting/subsequent treatment implies considerable handling of the wastes. Problems of corrosion, maintenance difficulty in the contaminated system, and uncertainty over the subsequent required treatment need to be resolved. The system would

work better in the winter, when ambient temperatures are low, and removal efficiency may not exceed reduced natural evaporation in the summer.

Without further study and increased knowledge of the parameters that so greatly affect success of the method, the process cannot be recommended at this time. One idea that needs to be researched further is use of a heat pump to freeze a portion of the wastes while the remainder undergoes enhanced evaporation.

### Influent Reduction

#### Technical Feasibility

A combination of two concepts are considered; filling and capping of those portions of the basin that are dry, and elimination of current waste influx. The former activity will be considered in greater depth, while only an indication of further study will be presented for the second concept. Taken together, these two processes have already been shown to result in effectively removing  $13 \times 10^6$  gallons of Basin F liquid per year. Since only simple, proven techniques are involved, the method is considered eminently feasible, of low risk and high reliability.

It is suggested that the techniques of wet air oxidation, biological reactors, activated carbon, and perhaps UV/ozonolysis be studied for treatment of the current waste stream, following chemical analysis to determine hazardous constituents and possible interferences.

Filling and capping would be accomplished annually so that the volume reduction enhancement is maintained. At the end of three years, a small 10-20 acre lake would result. The total solids content of the remaining waste would be around 60 percent, i.e., the result should be approaching a solid state. The residue should then be amenable to completion of the filling and capping process, with or without prior stabilization using lime or silicate methods as regulations dictate.

### Schedule

Design and construction are estimated to require less than 5 months for the initial effort and about 1 month for each subsequent phase of the fill.

### Costs

Essentially only earthwork would be required. Initially, approximately 400,000 cubic yards of fill would be required; depending on the source, this may cost up to \$ 300,000 to install. Subsequent fills would amount to about 150,000 cubic yards each, or \$ 112,500 annual "operating" cost. A clay cap one foot thick over the original 30 acres, or 50,000 cubic yards, is roughly estimated to cost \$ 35,000.

Note that the sum of these costs really need to be decremented by the cost estimate for ultimate filling and capping of the basin, since that fate is currently planned. This process in essence amounts to amortizing costs backwards over a 3-4 year period and thus represents a savings in real dollars.

### Regulation and Permit Requirements

Assuming that the acquisition of fill material is obtained in a sensible manner, the process suffers few incremental regulatory restrictions above that of the planned ultimate fate. A very slight change in surface drainage patterns over a 30-60 acre area is the greatest, albeit small, impact.

### Data Gaps

Other than confirmation of anticipated success by more carefully defined evaporation rates, few R&D requirements exist for this method, nor is sensitivity to current unknowns very great.

### Adverse Effects and Anticipated Problems

None, except possibly the length of time required for completion.

### Major Advantages

The primary advantages of this method are low investment costs, low energy requirements, direct applicability toward current Army plans, and very low technical risk.

### Surface Area Enhancement

The second method whereby the natural evaporation rate from Basin F could be effectively augmented is by increasing the current evaporative surface area. As currently envisioned, this method could involve a number of approaches including excavation and redistribution of soil in the present dry area at the South end; spray application of Basin F liquid to the dike above the dry area at the South end, spray aeration of Basin F liquid above the surface, or the construction of dikes to retain liquid within the dry areas.

### Technical Feasibility

The surface area enhancement method is technically feasible. The activities required to achieve an increase in evaporative surface area are essentially standard construction operations used routinely in industry. The technology required is in current use in the evaporation of brines from petroleum exploration and desalination plants. Because of the simplicity of the method and the established technology involved, the method is of low risk and of high reliability. By selecting the best approach, the evaporation rate can be increased by a minimum of 50 percent at very low cost. This increase, as well as the overall evaporation rate, will eventually be reduced as the Basin F liquid becomes more concentrated. However, the short term objective of enhancing the current rate of evaporation could certainly be achieved by this method.

After discussions with USATHAMA and RMA personnel, it is concluded that spray aeration, though technically feasible, would probably be difficult to implement owing primarily to local aesthetic and political factors. Excavation of the dry areas to increase the lake surface area is not recommended for two reasons:

- The difficulty and expense of operations involving excavation in the polluted areas. Problems occur due both to occupational health and safety aspects and the potential for windblown contamination.
- Destruction of the original basin liner would be required. Present condition of the asphalt membrane aside, even a remote possibility of increased short-term subsurface contamination to promote long-term benefits would not be a sound approach in view of the sensitivity of the issue.

The two surface area enhancement methods that remain to be considered involve pumping of the liquid and discharge either behind dikes or over the smooth dry area with subsequent flow back into the lagoon. Each offers an economical method for increasing the evaporative surface area, but differ somewhat in detail and cost elements.

The use of dikes was recommended in the simulated evaporation predictions of Shulman, et al.<sup>(40,41)</sup> Since these are unpublished reports, few details are given. However, apparently it was presumed that the collected rainfall behind the dikes did not pose a disposal problem and evaporation of this less concentrated but nevertheless highly contaminated volume was neglected in the simulation. If this is true, the evaporation rates thus obtained are in error; while the primary lake is effectively reduced at the same a "new" lake would be formed behind the dikes. The reason for this is the slope of the bottom which forces the pooling of water in a small area just behind the dike, whereas the precipitation influx occurs over the entire area behind the dike. If a new set of dikes were to be created each time the dikes were "moved" in the simulation, a problem arises in that the large number of dikes reduces the effective evaporation area. Whereas this latter situation could be solved with very small dikes, the original objective of impounding water would be destroyed by the high permeability of the barriers. Also, if an inordinate amount of earthenwork is contemplated within the basin, the same objections as were voiced relative to excavation of the dry areas apply.

It has been suggested that steel pile or simple impermeable barriers may be used for the dikes; this appears to be feasible since the evaporation surface is not significantly affected. However, anchoring of such a structure without impacting on the basin liner while maintaining a significant impoundment of the liquid would be difficult. If the dikes leak to any extent, the liquid must be continuously pumped to the higher elevations exactly as in the alternate system discussed below, and the advantage of installing dikes is questionable. On the other hand, if a relatively simple, low cost barrier can be designed, the energy costs would be low due to reduced pumping requirements, at the expense of periodic reinstallation costs.

The evaporation area can be increased simply by keeping the dry areas of the basin bottom wet. This is accomplished by pumping liquid from the lagoon and discharging it using low pressure nozzles to reduce erosion. The advantage of this method is the one-time, relatively inexpensive equipment installation. Potential problem areas include channeling of water return flow, particularly as salt buildup occurs in the dry areas.

Battelle suggests that the trickle method be used to enhance evaporation, primarily due to the one-time installation and low design costs. Since conduct of any operations within the confines of the basin is extremely hazardous, it is considered advisable to keep such tasks to an absolute minimum. However, it is recognized that the dike concept is technically feasible, and installation of dikes at a later time when the remaining lagoon materials become difficult to pump may prove useful. The latter factor would be of little import, however, if the basin can be filled before absolute dryness occurs.

### Costs

Surface area enhancement as described above should constitute a very economical method of reducing the volume of Basin F. Depending on the approach, the efforts involved would include earth moving, short sheet pile placement, and/or installation of a pumping and liquid distribution system. The costs of installation should be within the range of \$100K to \$300K. Operational and maintenance costs should not exceed \$100K per year. Installation could be accomplished within a 2 to 4 month period.

### Regulation and Permit Requirements

With the types of activities involved in enhancing evaporation by this method, additional permits should not be required. Therefore, no permit problems are anticipated. The surface area enhancement method does result in additional discharges to the air and, therefore, air regulations must be considered. Throughout this study it has been assumed that the total air discharges (those resulting from present and future enhanced evaporation) cannot exceed that which would result from Basin F if filled to its design capacity. Since this method is amenable to both design and operational control of the amount of liquid evaporated, problems which result from exceeding these discharge limits should not occur. Any further evaluation of air pollution dictates an analysis and monitoring of the vapor emissions from the basin.

### Data Gaps

There are no major data gaps which limit the application of this method to reducing the volume of Basin F. There are several unknowns which impact the design requirements; among these are:

- 1) present evaporation rate
- 2) required additional evaporation rate
- 3) amount of surface area enhancement required
- 4) relationship between evaporation rate and percent solids

### Anticipated Problems

The major anticipated problem is that of pumping as the Basin F liquid becomes more concentrated, although no problems are anticipated until the solids content reaches about 60 percent, at which time the chosen ultimate disposal technique may become applicable.

### Summary of Recommended Methods

#### Comparison

The recommended methods for reducing the volume of liquid wastes are:

- Influent Reduction
- Simple Evaporator
- Surface Area Enhancement

No attempt was made to rank these three methods, although it is apparent that the forced evaporation concept offers few advantages over the simpler, "natural" processes, whereas disadvantages of energy consumption, maintenance operating labor, and potential problems with corrosion and air pollution are evident. Strictly for comparative purposes, simple models volume reduction are presented in Figures 5 to 7. For these exercises, it was assumed that natural evaporation per unit area remained constant and process modification (e.g., additional fill in Influent Reduction) occurred once per year. The Evaporator design was assumed to be sized appropriately and to be about 50 percent efficient.

### Ultimate Disposal

#### Limitations of Study

In the short time available for this study it was not possible to research completely the impact of the planned ultimate fate of Basin F on each of the recommended methods for reducing the volume of liquid contents. However, several items of interest were defined and are presented below.



INPUT FROM PLANTS (EST.) =  $6 \times 10^6$  GPY

PRECIP. PER ACRE =  $0.4 \times 10^6$  GPY

<u>YEAR</u>	<u>ACRES FILLED</u>	<u>LAKE ACRES</u>	<u>GALLONS VOLUME ( <math>\times 10^6</math> )</u>
JAN 1979	0	74	110
JAN 1980	0	61	84
JAN 1981	36	54	72
JAN 1982	50	40	45
JAN 1983	62	28	24
JAN 1984	(70)	(20)	(9)

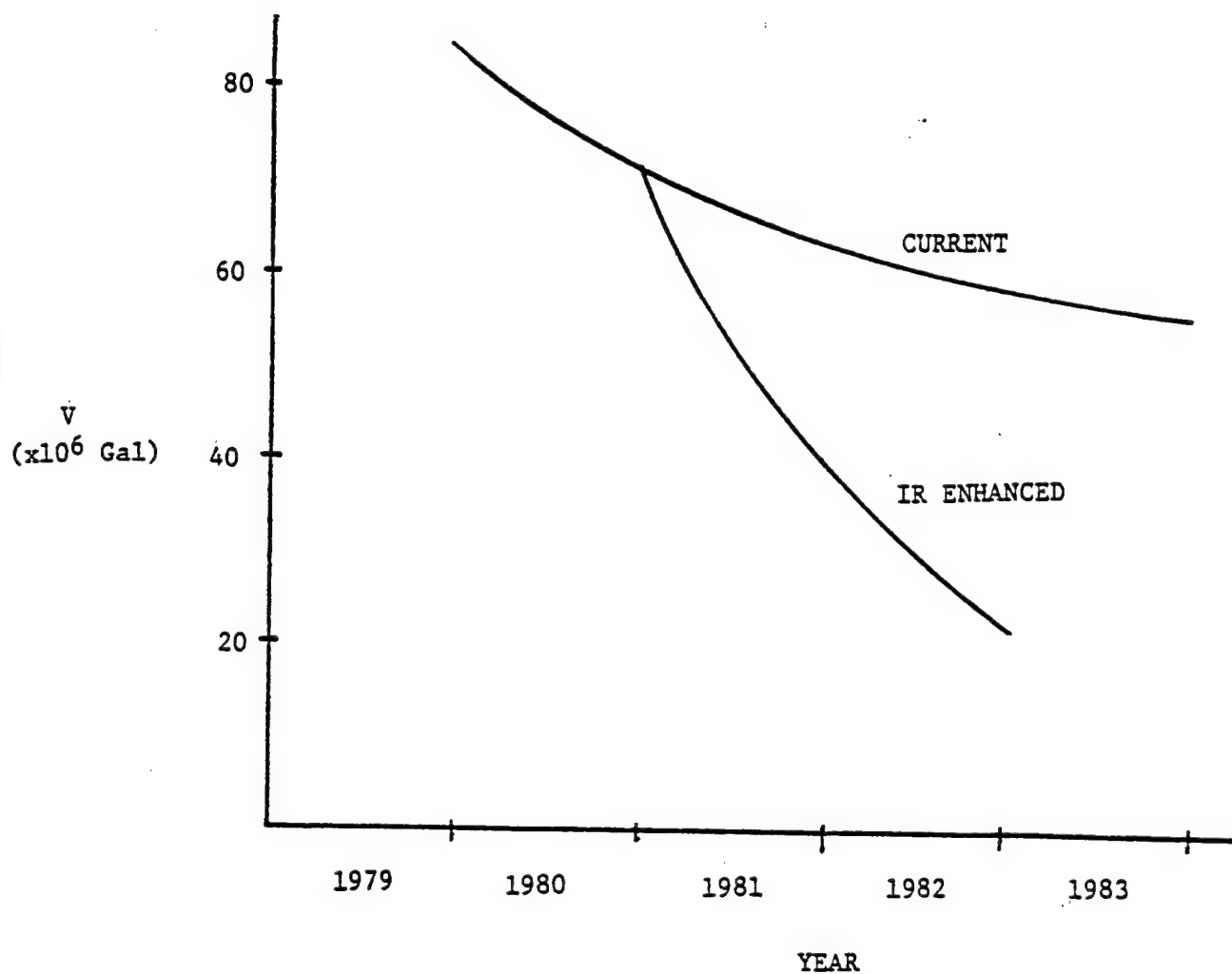


Figure 5. Influent Reduction

EVAPORATED VOLUME =  $16 \times 10^6$  GAL. PER YEAR  
HEAT REQUIRED =  $1.3 \times 10^{11}$  BTU/YEAR  
FUEL REQUIRED = 10,000 TONS OF COAL/YEAR

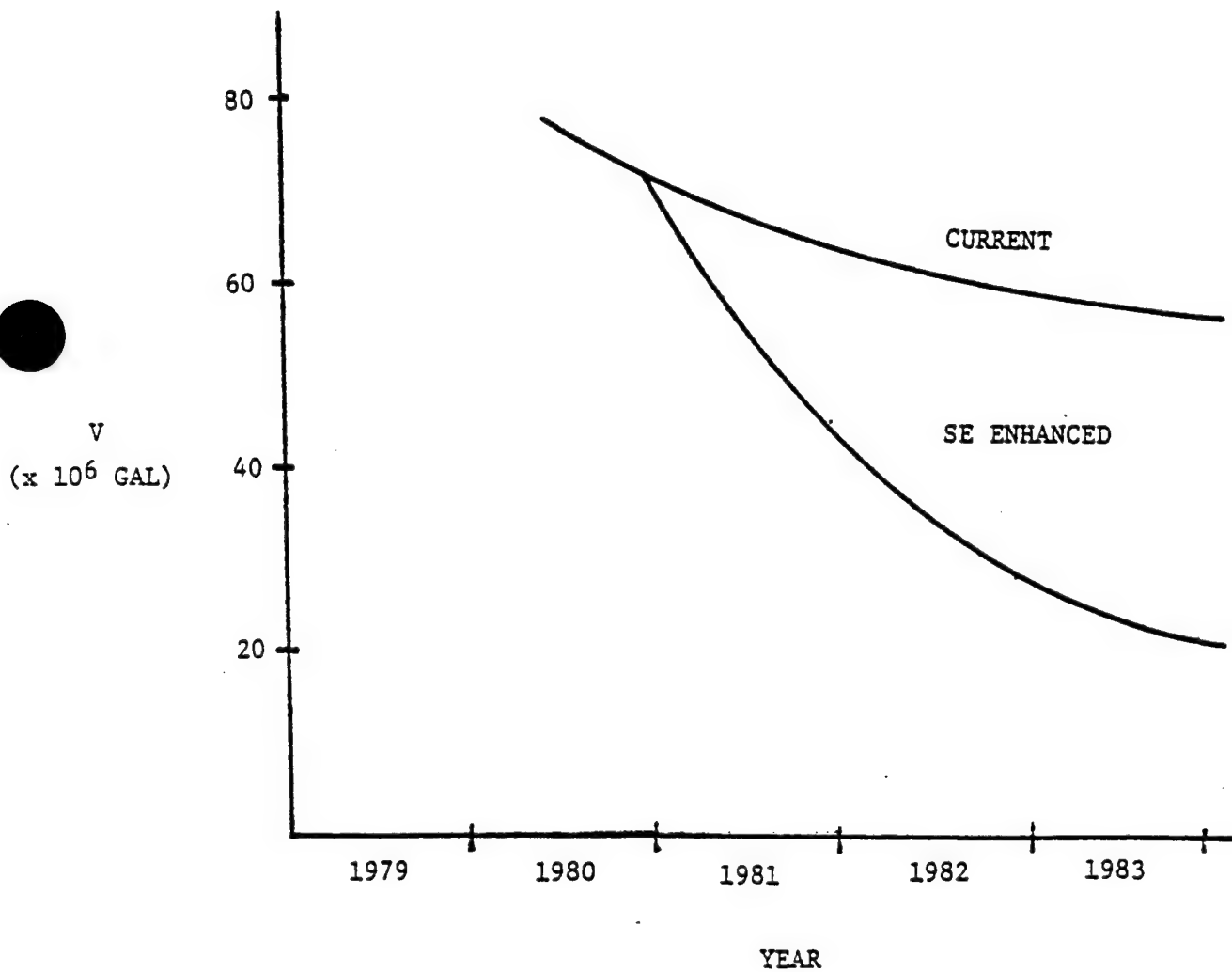


Figure 6. Simple Evaporator

STOP PLANT INFLUENT

JANUARY 81

START S.A.E.

JANUARY 81

S.A.E. = 90 ACRES - CURRENT VOLUME OF LAKE

<u>YEAR</u>	<u>LAKE ACRES</u>	<u>S.A.E.</u>	<u>GALLONS VOLUME (<math>\times 10^6</math>)</u>
JAN 1979	74	0	110
JAN 1980	61	0	84
JAN 1981	51	39	72
JAN 1982	29	61	26
JAN 1983	(0)	(90)	(0)

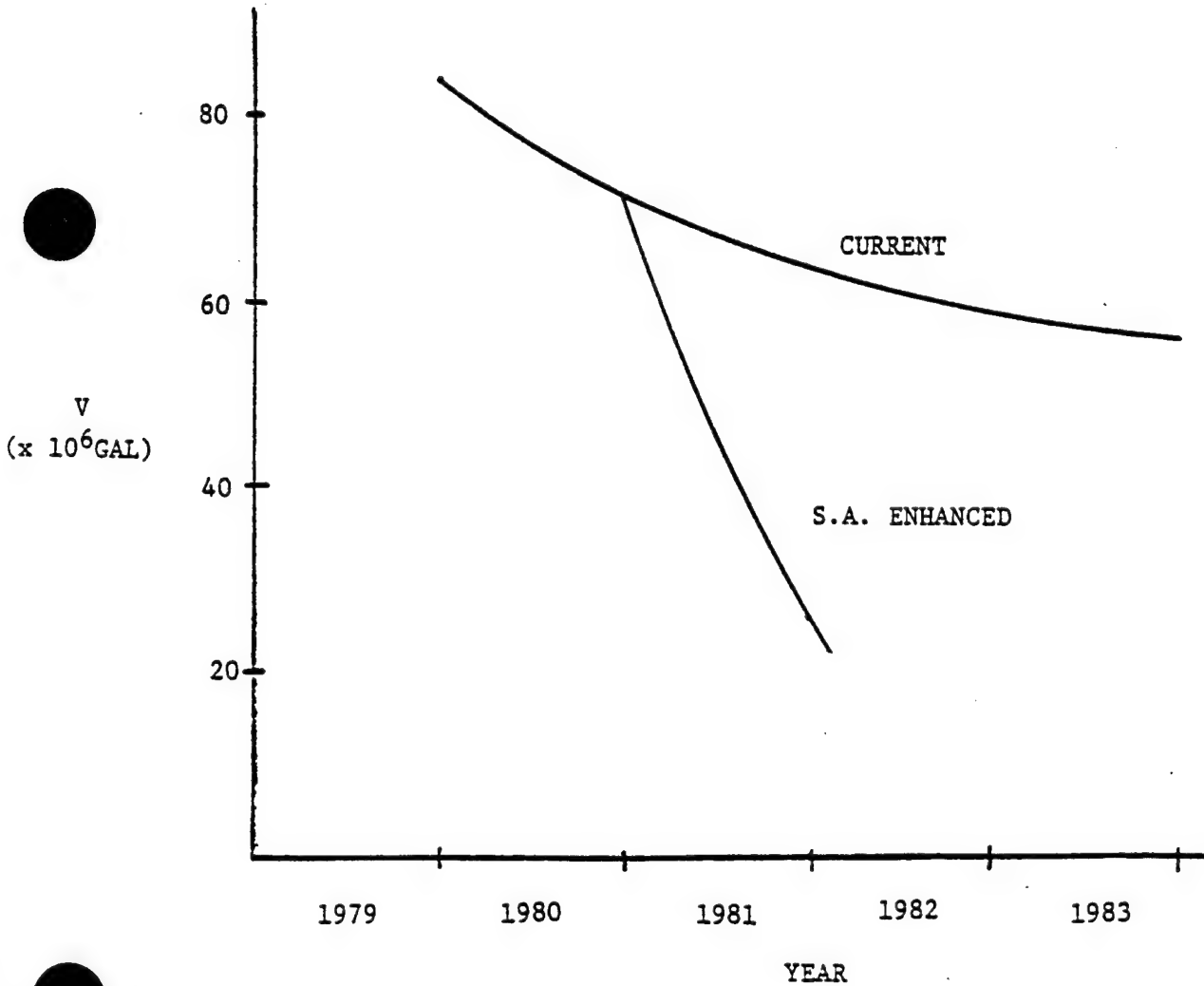


Figure 7. Surface Area Enhancement

### Impact of Regulations

It should be pointed out that the implications of the Resource Recovery and Conservation Act provisions on ultimate plans for treatment of Basin F may be very significant. As a minimum, it will likely be required to prove that planned activities are in compliance with the regulations and that alternatives to approved hazardous waste disposal methods offer the same or higher degrees of environmental protection. Depending on the outcome, standards for treatment and disposal or use of approved systems may be dictated.

The volume reduction process itself would not be at odds with the restrictions of RCRA, but it is likely that the ultimate disposal concept will be affected.

It is noted that none of the recommended methods for reducing the volume of Basin F address disposal of the hazardous wastes, and each assumes that the current plant for filling and capping the basin will be implemented; this is reasonable since part of the evaluation was directed toward that end.

The recommended methods, then, may not be acceptable in the light of the total proposed treatment and disposal plan. For this reason, it is recommended that actual destructive disposal techniques not be completely forsaken in research and development planning. If the regulatory ground rules change to any great extent, the results obtained in this task may be of purely academic interest.

None of the recommended methods result in discharge of liquid or solid waste streams, thus water pollution considerations are minimal. With respect to air pollution criteria, very little can be said since the constituency of vapors that are evolved during either forced or natural evaporation is unknown.

### Application Scenarios

Each of the processes studied have been evaluated against the task objective as essentially stand-alone, primary treatment methods. It may be more advantageous, however, to consider combined treatment

methods, and two suggested approaches are:

- Surface Area Enhancement or Influent Reduction to reduce the volume to approximately  $20 \times 10^6$  gallons (25 acre lake with maximum depth of 6 feet), followed by (a) chemical stabilization, (b) absorption in clay fill material, or (c) co-firing the remaining material with other residuals or wastes in an incinerator. The latter concept would require searching for a sizeable supply of combustibles; possibilities include municipal wastes, refuse from area Federal installations, and material undergoing demilitization. Air pollution control would be an important criterion.
- Wet Air Oxidation, followed by (a) biological treatment (b) activated carbon absorption or (c) land application of the residuals.

#### Recommendations for Further Study

#### Data Gaps

Despite more than twenty years of efforts, a great deal is not known about the chemical, physical, limnological and biological properties of Basin F. This situation is not unexpected; analyses and studies have been conducted generally in response to a specific and immediate need, and most of the geohydrologic studies have included evaluation of the more basic information only as it impacts the specific objective. At any rate, there is a general lack of information regarding many parameters upon which the applicability of a treatment process depends. These include:

- Evaporation rate studies of Basin F fluid.
- Complete Chemical Analyses: Liquid and Vapors
- Low and high temperature physical properties.
- Limnological studies, including biological studies and hazard criteria testing.
- Chemical analyses and discharge rates of plant effluent.

Table 7 shows the principal data gaps associated with each of the most promising treatment methods.

The degree to which firm data is lacking is far greater than originally surmized. Time and funding does not permit, therefore, preparation of detailed test plans for each of these areas. Included in Appendix 1 is a test plan for evaporation rate studies, i.e., those data requirements considered to be the most urgent. Appendix 2 contains outlines of experimental work taht needs to be performed for the other research and development tasks.

#### Pilot Studies

In view of the uneasiness with regard to whether present plans for ultimate disposition of Basin F will be acceptable from the regulatory standpoint, it is recommended that work on Wet Air Oxidation pilot scale processes proceed.

#### Other Studies

In addition to specific data requirements as outlined in the appendices, further study of the Basin F problem in relation to ultimate destruction and disposal is warranted. Consideration of the regulatory restrictions that would apply to the present plan, and the consequences thereof, should be made at the earliest possible time. It is strongly suspected that RCRA regulations may impact severely on the concept of filling the basin with the contaminants contained therein; whether the barrier concept will satisfy requirements is uncertain at present. The problem of disposal of dewatering fluid once the basin is filled needs to be addressed, as does treatment of the present RMA plant effluents and waste streams. These problems would best be evaluated simultaneously as parts of the overall situation; generally, the impact of individual tasks with restrictive workscopes cannot be well-defined. The study should commence

TABLE 7. FEASIBLE METHODS AND  
PRINCIPAL DATA GAPS

<u>METHOD</u>	<u>UNKNOWNNS</u>
WET AIR OXIDATION	TOTAL CHEMICAL ANALYSIS LARGE SCALE APPLICABILITY COMPOSITION OF PRODUCT ULTIMATE COST
FREEZE CONCENTRATION (ICE FARMING)	SECONDARY TREATMENT REQUIRED THERMAL BEHAVIOR OF THE FLUID PURIFICATION MAGNITUDE ULTIMATE COST (HIGH)
SIMPLE EVAPORATOR	EVAPORATION RATES VAPOR/LIQUID THERMOCHEMISTRY VISIBILITY OF CLOUDS ANALYSIS OF LIQUID/VAPOR
INFLUENT REDUCTION	TREATMENT OF WASTE INFLUENT EVAPORATION RATES ANALYSIS OF LIQUID VAPOR BATHYMETRY OF BASIN
SURFACE AREA ENHANCEMENT	EVAPORATION RATES ANALYSIS OF LIQUID/VAPOR BATHYMETRY OF BASIN

with a systems analysis and derivation of a model for the total RMA waste management problem. Owing to the shortening length of time before any new plans impact on milestone events, the study should be commenced immediately. This project could be conducted at the same time as, and perhaps in conjunction with, the recommended basic data acquisition tasks.

Several of the methods and processes studied above that were rejected as not meeting the immediate objectives of the current task need to be evaluated with respect to a role in the larger picture. Some of the techniques would work well in an overall waste management matrix, and many would find application in dealing with ultimate disposal. Economics and/or technical achievement can be envisioned to be improved through innovative combinations of techniques. For example, it appears attractive to use Second Law (heat pump) techniques to remove heat from a cold reservoir (freeze concentration) and deposit it in a hot reservoir (enhanced evaporation).

Many of the specific processes and approaches can be applied to more general U.S. Army decontamination and disposal problems dealing with biocides, explosives and pyrotechnics manufacturing, chemical agent demilitarization and wastes from other activities. The benefits of the recommended study thus transcend the immediate Basin F application.



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**APPENDIX 1**

## APPENDIX 1

### TEST PLAN PROCEDURE FOR COLLECTING MONTHLY EVAPORATION DATA ON BASIN F AT ROCKY MOUNTAIN ARSENAL, DENVER, COLORADO

#### Introduction

There are four generally accepted methods of estimating or computing evaporation from a body of water: (a) water budget, (b) energy budget, (c) mass transfer, and (d) evaporation pan. The most reliable methods are energy budget, mass transfer and evaporation pan. The extensive data requirements for the mass transfer and particularly the energy budget method render the evaporation pan method the simplest and most accurate method for estimating evaporation from an open body of water. Therefore, Battelle suggests that the U.S. Army initiate a program of more critically estimating the monthly evaporation loss from Basin F utilizing the evaporation pan method.

#### Description

The evaporation pan method estimates evaporation from a body of water by allowing the operator to calculate the daily amount of water evaporated from a standard surface. One can estimate the monthly volume of water loss through evaporation by summing the daily amounts evaporated from standard surface and multiplying the result by a coefficient which compensates for the increased evaporation from the shallow metal pan. The inches of evaporation so calculated is then converted into volume (acre-feet) by multiplying the inches of evaporation by the acres of surface areas of the lake. The acre-feet of evaporation loss is then converted to gallons of evaporation loss by multiplying by the appropriate conversion factor.

According to evaporation maps of the United States developed by the U.S. Weather Bureau the mean annual Class A pan coefficient for Denver, Colorado is 0.70. The mean annual Class A pan evaporation (for lake water) for the Denver, Colorado area is 60 inches. The mean annual lake evaporation for this area is about 41 inches. The above means are based on 10 years of data (1).

Two procedures are described below:

- Measurement of daily evaporation loss of Basin F fluid.
- Measurement of evaporation loss as a function of time (concentration), humidity, temperature, wind speed and solar flux.

### Equipment Required

The equipment required for estimating evaporation by the evaporation pan method is generally referred to as a National Weather Service type Class A evaporation station. This weather station consists of a Class A evaporation pan, a hook gage, a still well, a minimum/maximum thermometer and a contact anemometer. This equipment is available from several manufacturers including:

- (1) Weathertronics Inc.  
2777 Del Monte Street  
West Sacramento, California 95691  
Telephone (916) 371-2660
- (2) Weather Measure Corp.  
PO Box 41257  
Sacramento, California 95841  
Telephone (916) 481-7565
- (3) Science Associates, Inc.  
230 Nassau Street  
PO Box 230  
Princeton, New Jersey 08540  
Telephone (609) 924-4470

The cost of the above equipment should be about \$1,000 based on 1977 prices of \$800.

In addition, a 4 foot square wooden platform is required to serve as a base for the evaporation pan. The pan is normally located in an open, level area away from trees or buildings.

### Procedure For Measuring Water Loss

The procedure for measuring the daily water loss from the evaporation pan is presented below. This procedure covers activities from installation through calculation of the estimated gallons of water loss for a given month.

- (1) Select manufacturer and obtain necessary equipment (as discussed in the equipment required section).
- (2) Install pan and related equipment as specified by the manufacturer and determine that the evaporation station is functioning properly. The pan should be located as near coincidental to the surface of the Basin F lagoon as practicable.
- (3) Install still well with fixed reference point and fill the pan, with Basin F liquid, to the level of the reference point (about 2 inches from the top).
- (4) Record time of day (and other details) in log book.
- (5) Return to the evaporation station at approximately the same time the following day and record details of wind movement and water temperature.
- (6) Determine the amount of water loss during the observed time interval by adding enough Basin F liquid to return the water level to the fixed reference point within the still well.
- (7) Record the amount of liquid added to the pan (to the nearest 0.01 inch) as well as the time interval (to the nearest 5 minutes).
- (8) The amount of liquid added represents the evaporation loss for that time interval.
- (9) Calculate water loss on a per 24 hour basis using proportionality i.e. x inches in y hours: x inches in 24 hours.
- (10) Repeat steps 5 through 9 for each day of the month.
- (11) Add the 24 hour evaporation totals for each day of the month to determine the measured inches of evaporation loss for that month.
- (12) Determine the inches of estimated water loss from Basin F for the month by multiplying the measured inches of evaporation loss (Step 11) by the mean annual Class A pan coefficient which is 0.70 for the Denver, Colorado area.

- (13) Determine the estimated acre-feet of evaporation loss for the month from the total surface area of Basin F by multiplying the inches of estimated water loss (expressed as feet) by the measured surface area of Basin F for that month (expressed as acres).
- (14) Determine the monthly evaporation loss from Basin F in gallons by multiplying acre-feet (Step 13) by  $3.258 \times 10^5$  (the conversion factor for acre-feet to gallons).
- (15) Record the data as well as the procedure used to obtain the data in a log book.
- (16) At the end of each month, empty and clean the pan and repeat from Step (3).



### EXAMPLE DATA SHEET

<u>Date</u>	<u>Time</u>	<u>Operator</u>	<u>Temperature</u> <u>Basin Pan</u>	<u>Wind Speed</u> <u>(M/S)</u>	<u>Liquid</u> <u>Added(min.)</u>	<u>Time</u> <u>Interval</u> <u>(min.)</u>	<u>Evap. Loss</u> <u>(24 hrs)</u> <u>(inches)</u>
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### EXAMPLE COMPUTATION SHEET

<u>Month-Year</u>	<u>Pan</u> <u>Evaporation Loss</u> <sup>1</sup> <u>(feet)</u>	<u>Basin</u> <u>Surface Area</u> <sup>2</sup> <u>(acres)</u>	<u>Pan</u> <sup>3</sup> <u>Coefficient</u>	<u>Basin</u> <u>Evaporation Loss</u>		
				<u>Feet</u> <sup>4</sup>	<u>Acre-feet</u> <sup>5</sup>	<u>Gallons</u> <sup>6</sup>
7/80	0.268	62.8	0.70	0.188	11.71	$3.82 \times 10^6$

Calculations:

1. Divide total monthly evaporation loss by 12
2. Obtained from survey on 15th of each month.
3. Constant = 0.70
4. Multiply 0.268 feet by 0.70 = 0.188 feet
5. Multiply 62.3 acres by 0.188 feet = 11.7 acre-feet
6. Multiply 11.71 acre-feet by  $3.258 \times 10^5$  gal/ac.ft. =  $3.82 \times 10^6$  gal.

## Procedure for Measuring Evaporation Rates

### Equipment Required

1. Class A evaporation pan as described above, with still well and hook gage.
2. Continuous 24 hour recording meteorological weather station, including wind speed; temperatures of lake, pan, and air; humidity; precipitation gauge, and solar flux meters.

### Scope

1. Install pan and meteorological station in accordance with manufacturers directions.
2. Verify procedure, technique and statistical validity by observation of the evaporation rate of distilled water.
3. Perform rate measurements on Basin F fluid.

### Procedure

1. Install still well and hook gauge in pan. Fill with liquid to the reference mark and record reading of hook gauge. Begin operation of meteorological instrumentation.
2. Thrice daily (0800 hours, 1200 hours, and 1600 hours), record the meteorological parameters from the records and the hook gauge reading of liquid level in the pan. Change 24-hour recording charts each day at the 0800 hour test operation.
3. Mark each chart with a unique test number (recorded in logbook), date and operator when installed. Place charts in a file marked by test number and date when they are removed from the recorders.
4. Record observations of fluid conditions each day at the 0800 hour reading in the Remarks column. Attention is directed toward color, scum formation, crystal growth, turbidity, etc.

5. As directed, 100 ml samples of the pan contents will be removed from time to time by the Chemical Laboratories.
6. Submit all data and records each week to the Chemical Laboratories.
7. As directed, empty, clean, refill the pan, and begin a new test sequence from Step 1.

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**APPENDIX 2**

**DATA REQUIREMENTS**

## APPENDIX 2

### DATA REQUIREMENTS

#### I. EVAPORATION RATE STUDIES (See Appendix 1)

##### A. CURRENT EVAPORATION RATES AS A FUNCTION OF:

- TEMPERATURE: AIR AND WATER
- WIND SPEED
- BAROMETRIC PRESSURE
- RELATIVE HUMIDITY
- SOLAR FLUX

##### B. EVAPORATION RATE AS A FUNCTION OF CONCENTRATION, INCLUDING OBSERVATION OF SCUM OR SOLID SURFACE LAYER.

#### II. MAJOR ORGANIC CONSTITUENTS

##### A. LIQUID PHASE QUALITATIVE SCREENING AND QUANTITATIVE ANALYSES.

##### B. VAPOR PHASE QUALITATIVE SCREENING AND QUANTITATIVE ANALYSES.

#### III. HAZARDOUS WASTE CHARACTERISTICS

##### A. IGNITIBILITY

##### B. CORROSIVITY

##### C. REACTIVITY

##### D. TOXICITY

##### E. MUTAGENICITY/TERATOGENICITY

##### F. RADIOACTIVITY

IV. PHYSICAL PROPERTIES

- VAPOR PRESSURE VS TEMPERATURE
- HEATS OF VAPORIZATION AND FUSION
- THERMAL CONDUCTIVITY AND DIFFUSIVITY
- EFFECTS ABOVE AS A FUNCTION OF CONCENTRATION.

V. CHEMICAL ANALYSIS AND RATE OF PLANT EFFLUENT

VI. LIMNOLOGICAL STUDY

BATHYMETRY, HEAT BUDGET AND WATER MOVEMENTS, LAYERING AND  
CIRCULATION, BIOTA AND PRODUCTIVITY, ADAPTATION POTENTIAL,  
SPECTRAL ABSORPTION AND SOLAR PENETRATION, OXYGEN AND  
CO<sub>2</sub> PROFILES.

VIII. WET AIR OXIDATION PILOT STUDIES.